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A Water Geochemistry Study of Indian Wells Valley, Inyo and Kern Counties, California
Volume 1. Geochemistry Study and Appendix A

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(U) The geochemistry of groundwater in Indian Wells Valley (IWV) was studied using water analyses available from the U. S. Geological Survey supplemented by samples taken by the University of Utah and the Naval Weapons Center (NWC). The geochemical findings reveal possible sources of leakage of geothermal waters into the IWV.

(U) In the IWV and related areas, of 254 water types possible, some 55 are present. By grouping similar types of water together, eight major water types were mapped:

1. Alpine waters (calcium-sodium-magnesium-bicarbonate type)
2. Sodium-chloride waters
3. Sodium-carbonate waters
4. Sodium-bicarbonate waters
5. Sodium-bicarbonate-chloride waters
6. Sulfate waters
7. Red Hill/Little Lake/Lumber Mill Waters (calcium-(sodium-magnesium)-bicarbonate-chloride-(sulfate)) waters
8. The waters of the well fields (usually sodium-calcium, but sometimes calcium-sodium-bicarbonate-chloride)

(U) Geothermal leakage into IWV occurs from Coso, areas west and just north and south of the main gate of NWC, the southwestern part of the IWV, and Haystack Peak in the Spangler Hills. (Contd. on back)

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(U) Thrust faulting and associated listric, landslide, and relaxation faulting in the Sierra, the Coso and Argus Ranges, and under the IWV provide other avenues for subsurface inflow. Data indicate significant inflow into the IWV from Rose Valley. Inflow from the Sierran granitics is indicated by the Tungsten Peak Mine, which produced 180 acre-feet of water per year when in operation. Besides evaporation from China Lake Playa and transpiration by plants, other possible losses from the IWV are subsurface outflow to Searles Valley through Salt Wells and Poison Canyon, interbasin flow to Searles Valley beneath the Argus Range, and interbasin flow south towards Koehn Lake.

(U) With the exception of a few wells in the Ridgecrest field, water quality has changed little with time. Water quality may improve, deteriorate, or remain constant with depth, depending on well location.

(U) The geochemical data of this report, when integrated with the structural and other data, may point to additional critical sites that should be sampled.

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ACKNOWLEDGMENTS

INTRODUCTION

This report summarizes the results of a study of the geochemistry of groundwater in Indian Wells Valley and uses the geochemical results to make inferences about possible leakage of geothermal waters into the Valley. The Eastern Kern County Resource Conservation District (EKCRCD) supported much of the geochemical studies with a generous grant to the Department of Geology and Geophysics, University of Utah. Additional chemical work and evaluation of geothermal potential was done by the Geothermal Program Office, Naval Weapons Center (NWC), China Lake, California.

Groundwater studies have been done in Indian Wells Valley since those of Lee (1913) to the present (see the section Previous Studies). These studies are of varying quality. In addition to the nearly 1,200 water analyses taken from previous studies, 23 new sites were sampled for water analysis. In total, over 370 sites were sampled (many with numerous analyses) for this study. The EKCRCD and the Geothermal Program Office realized that groundwater alone is but one component of the local geological environment and that to adequately understand groundwater, the total geological environment must be understood. For that reason, the studies conducted by these two organizations included studies of structural geology and shallow heat flow, this study of water geochemistry, and water isotopes. The isotope studies will be published later. As far as we know, these various studies combined are the first truly integrated study of a groundwater system in a desert basin. Appendixes A through G of this report offer more detailed and extensive information on work done for this study.

Indian Wells Valley is located in eastern Kern County, southern Inyo County, and northwestern San Bernardino County (Figure 1). The principal settlements in the area are Ridgecrest, China Lake, Inyokern, and Little Lake. The largest employer in the area is NWC. Commissioned in 1943, the Center employs approximately 5,000 civilians and 1,000 military personnel, and directly supports approximately 2,500 contractor personnel in the Valley.

CONVERSION FACTORS

The results of chemical analyses and temperatures in this report are given in metric units rather than the more familiar English units. Concentrations are reported in milligrams per liter (mg/L) or micrograms per liter (μg/L), and water and air temperatures are reported in degrees Celsius (°C).

Milligrams per liter is numerically nearly equal to the unit parts per million (ppm) for concentrations of less than about 7,000 mg/L. Parts per million was formerly used by the USGS to report the results of its chemical analyses.

Micromhos per centimeter is now reported as microsiemens per centimeter. The quantities are equivalent and the nomenclature is interchangeable.
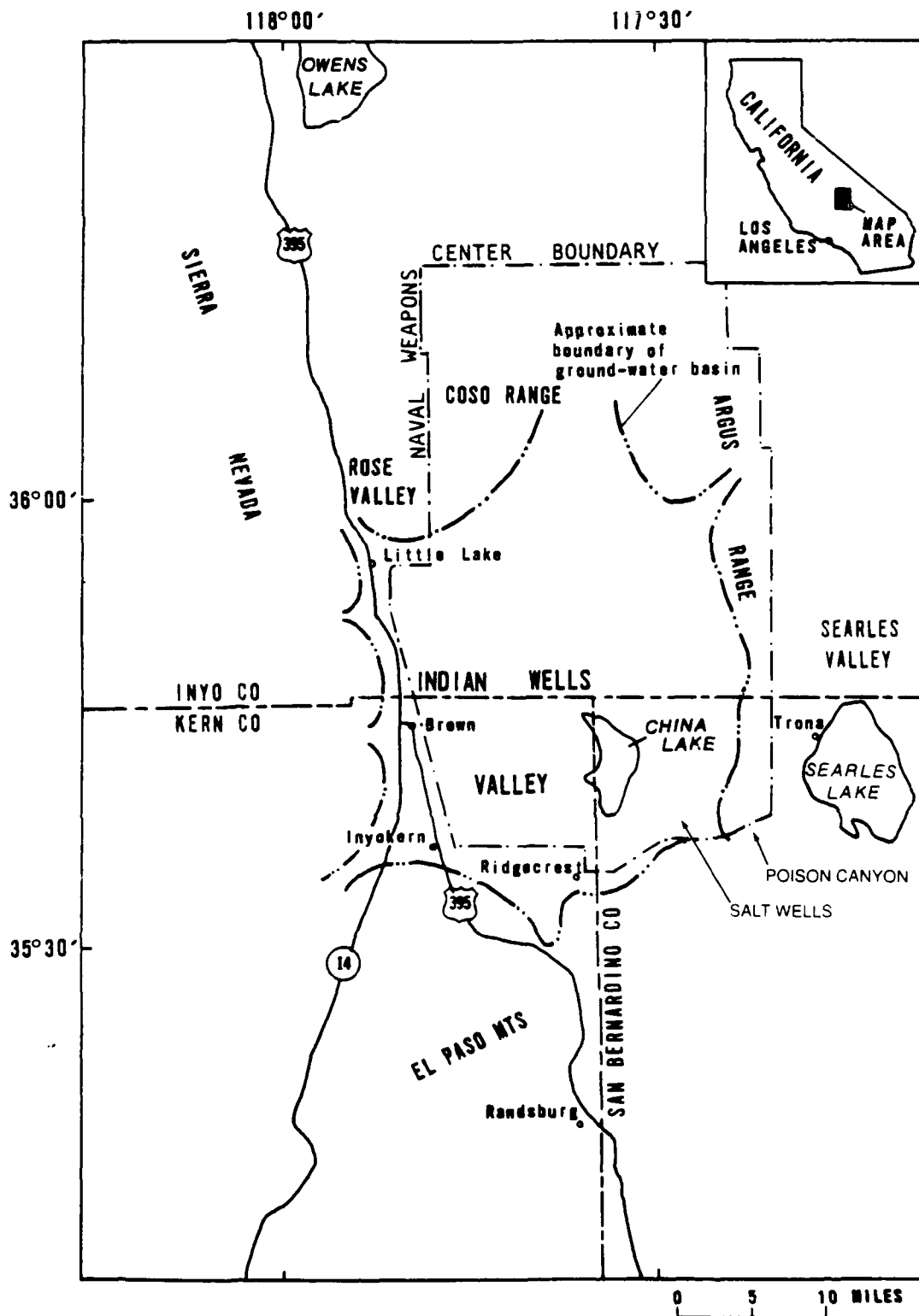
FIGURE 1. Location of the IWV Groundwater Basin
(Modified From Lipinski and Knochenmus, 1981).
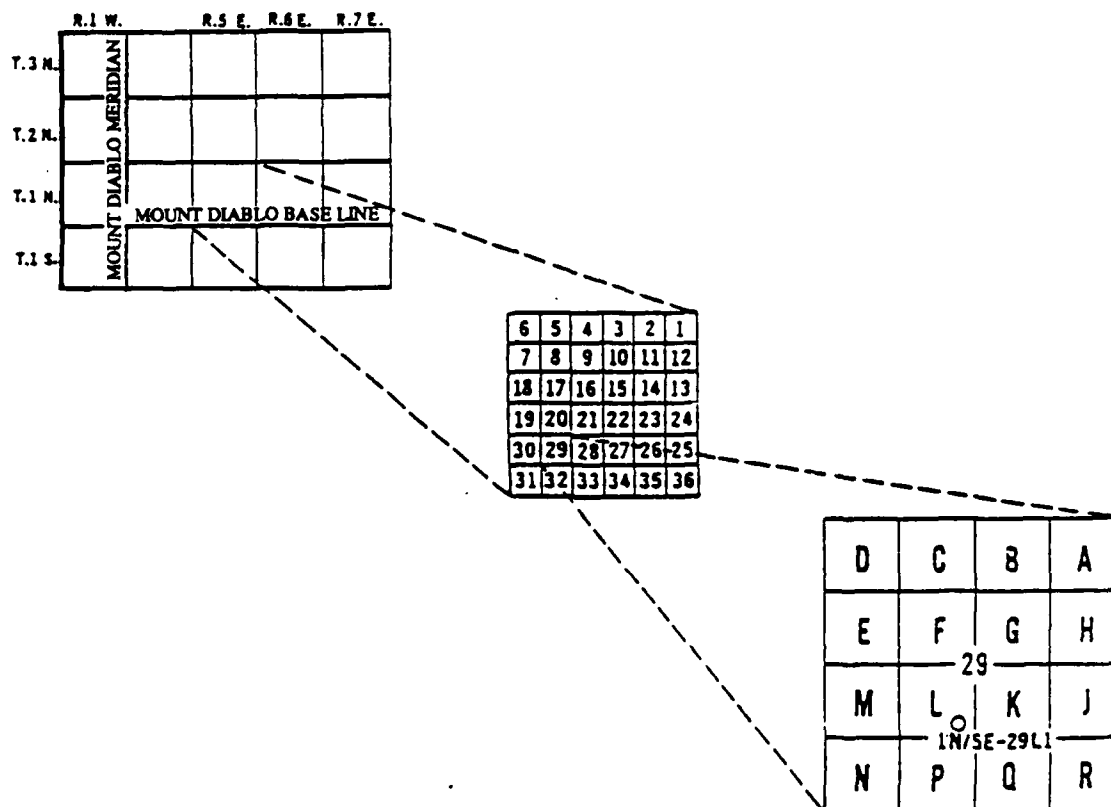
FIGURE 2. Diagram Showing Relationship of Township, Section, and Subdivision for Locating Well Sites Using USGS Well-Numbering System.

WELL-NUMBERING SYSTEM IN CALIFORNIA

Figure 2 shows the relationship of a township, section, and subdivision for locating well sites using the USGS well-numbering system. Well locations in this report are given in this format.

The USGS well-numbering system used in California indicates the location of wells according to the rectangular system for the subdivision of public land. This rectangular system is based on divisions called townships, which are 36 square miles (although the size can vary considerably in actual practice) and are numbered according to their relationship to a base line and a meridian. The townships in Indian Wells Valley are measured from the Mount Diablo Base Line and Mount Diablo Meridian. In Figure 2, the Mount Diablo Base Line provides the north-south reference and the Mount Diablo Meridian provides the east-west reference. For example, T1N/R5E is one township north of the Mount Diablo Base Line and is five townships east of the Mount Diablo Meridian.

Well numbering follows the township-numbering system and uses further, more specific, designations. Figure 2 shows the location of well number 1N/5E-29L1; the first numbers and letters designate the township (T1N) and the range (R5E),; the third number gives the section (sec. 29); and the letter indicates the 40-acre subdivision of the section. The final digit is the serial number assigned to this particular well; the wells in each 40-acre subdivision are given serial numbers to identify them within that subdivision.

CLIMATE OF THE INDIAN WELLS VALLEY

Climatological data were obtained from the Final Environmental Impact Statement, Proposed Leasing within the Coso Known Geothermal Resource Area (Bureau of Land Management, 1980). The climate of Indian Wells Valley, typical of the southern California high desert region, is characterized by hot summers, cool to cold winters, large diurnal temperature changes, low humidity, and little cloudiness or visibility restrictions other than occasional blowing dust.

Local topography is an important climatic factor. The Sierra Nevada mountains to the west form a barrier to passing storms and frontal systems, and create a rain shadow effect. The air is warmed as it descends down the lee side of these mountains, and the potential for condensation is decreased. As a result, precipitation varies from 20 to 55 inches on the windward (west) side of the Sierra to less than 10 inches annually on the east side. Annual average precipitation in the center of the Indian Wells Valley is about 3 inches.

Snowmelt is an important part of groundwater recharge in the Indian Wells Valley area. The Bureau of Land Management has developed a formula to predict snowfall based on elevation:

$$Y = 0.57 \times e^{1.51} \times 10^{-3} \times X$$

where

X = elevation in feet
Y = the average annual snowfall in inches

The correlation coefficient was 0.84. Nine inches of snow is equivalent to about 1 inch of water. The average of the mean annual temperature at the NWC weather station is 64.0°F. Monthly normal temperature range is from 43.1°F in January to 86.2°F in July. The daily temperature extremes show a normal daily minimum in January of 28.7°F while the normal high of 102.3°F occurs in July. The 50% probability date of the last spring frost is around April 1.

The mean monthly relative humidity values at China Lake range from 23% in July to 52% in December. There is an average of 74 days (20.3%) per year of total cloud cover, with a maximum number of cloudy days per month during the winter season and a maximum number of clear days per month during the summer and early fall seasons.

Prevailing winds are from the south-southeast or north-northwest at all times of the year. Long-term data show average annual wind speed at China Lake to be 8.2 mph, with the highest monthly average (10.4 mph) occurring in May. There are occasionally high winds from the north and from the west, the strongest ever recorded in China Lake was 81 mph in March 1952.

Summer thunderstorms are not uncommon; localized torrential rains and flash flooding can occur from June through October. Every few years, heavy lasting summer rains occur when a hurricane off Baja California pumps moisture into the area and traps it against the east side of the Sierra, temporarily reversing the rain shadow effect.

PREVIOUS STUDIES

Many studies of varying length and quality have been done of groundwater in the Indian Wells Valley. None, however, addressed the regional groundwater flow system or groundwater flow system cells (areas of groundwater types) to any extent.

The earliest studies were those of Lee (1913). Another early study of groundwater was that of Whistler (1923). The first USGS study of the area was that of Thompson (1929). He published some analyses and proposed a water budget for the basin. The first Navy study of groundwater was that of Buwalda.*

In 1951, Wilcox, Hatcher, and Blair published a paper on the quality of water of the Indian Wells Valley.

In 1959 Dutcher published data on water wells in the Fremont Valley area. In 1963 Moyle published data on water wells in Indian Wells Valley area. His publication contains available well data and 220 water analyses (not all complete). Quality control over the analytical work appears to be good.

Findings of Kunkel and Chase. Kunkel and Chase (1955), in a USGS study for the Navy, calculated a water budget; supporting tables are available in Kunkel, Chase, and Hiltgen (1954).

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* Buwalda, J. P. 1944. *Underground Water Supply in Indian Wells Valley*, for Inyokern Naval Ordnance Test Station: unpublished report to Commanding Officer.

In 1969 Kunkel and Chase published a USGS open-file report entitled "Geology and Ground Water in Indian Wells Valley, California." (See the Geology section of this report.)

Kunkel and Chase did not have either the number of analyses now available or the present computer capabilities. They grouped different waters together based on a scheme involving 50% of the milliequivalents (1969, p. 51). They compare their Group I waters (low total dissolved solids (TDS) sodium-carbonate waters with low fluoride and boron) to the alpine waters and place this group in the Inyokern well fields and areas to the north. (For a discussion of what exists north of Inyokern, see the sections on sulfate waters and Red Hill/Little Lake/Lumber Mill site waters in the Water Types section.)

Waters classed Group II are also sodium-carbonate waters of low TDS but with higher boron and fluoride contents. Kunkel and Chase place these waters from the main gate of NWC to about 1 mile north of the intermediate well field. They consider their Group II waters to be alpine waters modified by base exchange (ions from water going into a mineralized zone releasing different ions into the water). They attribute the minerals with exchange properties to be zeolites. We believe that clays in the alluvium and valley sediments are more probably the minerals exhibiting a base-exchange potential.

The waters classed Group III are sodium-chloride waters. These, of course, include waters in and near China Lake playa (a dry lake) and waters to the south and east of Ridgecrest. Kunkel and Chase postulate a clay barrier restricting the movement of the latter waters eastward. They attribute the sodium-chloride waters south and east of Ridgecrest to come from a former lake or lakes in the area. An alternative explanation, geothermal leakage, is discussed in the Summary.

Kunkel and Chase presented conclusions on the water budget of the valley based on both data and extensive assumptions.

Calculating a Water Budget. Conclusions on any water budget will vary depending on the quality of the data and the assumptions made. Calculating a water budget is beyond the scope of this paper. Some data possibly affecting assumptions are contained in the conclusions section of this report. A 1988 critical review given by Dr. C. F. Austin, NWC Geothermal Program Office, of the various water budgets published for the Valley was published verbatim by the *News Review* of Ridgecrest, California.*

USGS Reports. The USGS has published several open-file reports in cooperation with NWC to update observations on water levels and to furnish water analyses for 1 year or a few years. Among these reports are Koehler (1971), Banta (1972 and 1974), Lamb and Downing (1978), and Berenbrock (1987).

Other Documents. The Geothermal Program Office, Public Works Department, NWC, maintains a Coso library open to the public. In addition, the California Energy Company, Inc., the geothermal developer at Coso, has much proprietary information on the geothermal reservoir and the hydrology and structural geology of the entire region.

In the Coso Geothermal Field the principal geothermal brines are of the sodium-chloride type, and the recharge area is the Sierra (Fournier and Thompson, 1980). Some additional significant references are Austin and Pringle (1970), Moyle (1977), and Spane (1978).

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* Copies are available from the NWC Geothermal Program Office upon request.

In 1975, Warner, in a USGS report, stated that the dissolved solids conten* in some areas was increasing slightly, however, where this had occurred it was not yet serious.

In 1971 Bloyd and Robson published a paper entitled "Mathematical Ground-Water Model of Indian Wells Valley, California." Austin (1987) wrote a critical review of the concepts in this paper.

In 1973, Dutch r and Moyle published the water-supply paper "Geologic and Hydrologic Features of Indian Wells Valley, California."

In 1984, Dr. Pierre St. Amand proposed that the Indian Wells Valley groundwater system is a closed basin, and he prepared a water budget for the basin on that assumption.*

GEOLOGY

The Sierra Nevada mountains to the west of India 1 Wells Valley consist of granitic rocks with roof pendants of metamorphic rocks. Some contact metamorphic rocks also occur (such as the Tungsten Peak Mine). The Coso Range to the north is complex; Sierran basement rocks have been penetrated by both basaltic (dark colored, low silica) and rhyolitic (light colored, high silica) volcanic rocks of Tertiary to recent age. An excellent surface map of the Coso Volcanic Field is that of Duffield and Bacon (1981). The Argus Range locally to the east and the Spangler Hills to the southeast are also predominantly Sierran basement type rocks. The El Paso Mountains to the southwest are also Sierran but contain Eocene (Tertiary) basalt and both continental and marine sediments, and considerable Paleozoic marine sediments. The USGS authors from the various groundwater offices that have reported on the Indian Wells Valley in the past 2 decades have all considered the bedrock to be impermeable and largely non-water bearing. The permeability of plutonic and volcanic rocks is discussed in the Summary.

The Valley itself is traditionally considered to consist of alluvium, lacustrine (lake) deposits, windblown sands, playa silts and clays, and probably a thick section of estuarine and marine sediments at depth. However, careful field work on the east face of the Sierra shows that much of the composition should be glacial tills and glacial outwash debris (Austin, 1988). The alluvium on the west side of the valley in particular occurs as alluvial fans and glacial outwash debris coming into the valley from mountain canyons and valley fill. Kunkel and Chase (1969) divide the valley alluvium into "older" and "younger" units and give them formation names. The lake deposits are Pleistocene (Ice Age) and are interbedded within the alluvium. Kunkel and Chase proposed a simple stratigraphy with the older and younger alluvium deposits separated by the older lake deposits (young lake deposits are represented by the pinnacles in Searles Valley). The Tertiary and Pleistocene was a complex age. Austin (1988) suggests that the pluvial periods documented by Norris and Webb (1976) have all affected the Indian Wells Valley.** Austin lists the following glacial events, presented here as Table 1.

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* January 1984 draft copy of NWC TP 6404, "The Water Supply of Indian Wells Valley, California," published in 1986.
** Dr. C. F. Austin, personal communication with Dr. J. A. Whelan, 1988.

TABLE 1. Glacial Periods.

(From Norris and Webb, 1976).

Name of period	Years before present
Matthes	0-650
Unnamed	1,000
Recess Peak	2,000-6,000
Unnamed	6,000-7,000
Hilgard	11,000
Tioga	20,000
Tenaya	26,000
Tahoe	50,000
Mono Basin	87,000
Donner Lake	250,000
Casa Diablo	400,000
Sherwin	750,000
McGee	1,500,000
Deadman Pass	3,000,000

In 1984 the geology was determined of a well drilled by the Navy just inside the NWC boundary by the Inyokern substation (Whelan, unpublished report, 1984). Tree rootlets were encountered at 400 feet. At greater depths in this 1,000-foot well were two zones where the alluvium was cemented with caliche. Whelan assumed these to be "splash" zones formed at a shoreline. If his interpretation is correct, separate lakes were present there twice, or one lake was transgressing and regressing. In either case, the valley fill is highly complex as well as folded.[*] Scattered local confined zones may exist but there is no evidence that the basin as a whole has any recognizable division into broad horizontal layers of different kinds of waters.

Works of the USGS considered Indian Wells Valley to be a simple down-faulted block bounded by high-angle faults. Zbur (1963), on the basis of seismic refraction, gravity, and aeromagnetic studies, postulated a maximum of 6,200 feet of valley fill. However, he also assumed the valley was bounded by high-angle faults. Austin and Moore (1987) presented convincing evidence that the Coso Range was formed by low-angle thrust faulting. More and more evidence is surfacing that the Sierra and Argus Ranges are both stacked thrust sheets complicated by major listric faulting.[**] Certainly thrusting is important throughout the Basin and Range geologic province and also into the Colorado Plateau.

If, as now seems probable, thrust faulting has been important in local geologic history, then the basement under the valley fill in Indian Wells Valley could well be sedimentary rocks.[***] This possibility has significant implications as to both regional groundwater

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[*] Dr. C. F. Austin, Ward Austin, and D. O'Brien, personal communication with Dr. J. A. Whelan, 1988.

[**] R. Erskine, personal communication with Dr. J. A. Whelan, 1988.

[***] D. O'Brien, personal communication with Dr. C. F. Austin, 1988.

hydrology and the complex pattern of groundwater flow system cells in the valley. See the section Determination of Groundwater Flow System Cells for more information.

The basic geologic map of the area is the Trona Sheet, Geologic Map of California (Jenkins, 1962). Nilsen and Chapman (1971) prepared the Bouguer gravity map of California, Trona Sheet. Jenkins and Nilsen and Chapman did not recognize the thrust faulting in the Coso Range or Sierra (Austin and Moore, 1987).

THEORY BEHIND GEOCHEMICAL INVESTIGATIONS

The quality of natural water is determined by the concentrations and types of dissolved material contained within the water. The dissolved material in the water may have been derived from the atmosphere, biological sources, soils, or minerals, or through human-induced activities. Bacteria, evaporation, mixing, and chemical reactions may further alter the water as it passes through the hydrologic cycle. In the Indian Wells Valley, widespread geothermal activity is a major contributor to the groundwater chemistry.

To determine the chemical quality of water, an analysis must be performed on the sample. This analysis involves both the careful measurement of certain parameters of the water sample as it is taken from its natural environment and the proper preparation of the sample for later analysis so that the concentrations of the dissolved ions do not change.

ON-SITE MEASUREMENTS: TEMPERATURE, pH, AND CONDUCTIVITY

On-site measurements at the sampling source include temperature, pH, and conductivity. These three parameters can change rapidly with time and must be measured as soon as the sample is taken.

Temperature

Temperature readings of groundwater are an important source of information. Many factors concerning the measurement and actual ionic composition of water quality are influenced by temperature, including pH, conductivity, and the concentration of dissolved ions. Temperature readings must be included in corrections for pH and conductivity because both are based on a certain property of the water at a specific temperature.

Temperature readings are also important in the Indian Wells Valley because of the known presence of geothermal features in close proximity to or within the valley. Geothermal features may contribute heat or heated water to the local groundwater system and cause major changes in the chemistry of the water. If an abnormally high temperature were measured at a sampling location, that would indicate that the groundwater reservoir was connected in some way with a higher-than-normal heat-flow area. For example, water from a Navy well at the Inyokern substation is 27°C. Thus, a geothermal area may be contributing heat to the local reservoir, or geothermally altered waters may be mixing with the more typical groundwaters. An analysis of certain constituents that are found in geothermal waters compared with analyses of neighboring non-geothermal waters is

sometimes a fairly reliable method of determining if an intermixing of waters is occurring in the area. This method will be discussed in the Water Types section of this report.

Measuring pH

The measure of pH in a sample must also be taken immediately after the water is removed from its natural environment. Reported in the base 10 log of the hydrogen ion activity (in moles per liter), pH gives an indication of the type and amount of reactions the water was undergoing at the time of sampling.

The pH values change as hydrogen ions are produced or consumed during chemical reactions in the groundwater system. Values of pH are commonly lumped into three major divisions: basic (pH > 7.0), neutral (pH = 7.0) or acidic (pH < 7.0). A water containing equal amounts of hydrogen ion and hydroxide ion ($H^+ = OH^-$) at 25°C has a pH of 7.00. If hydrogen ions are added to this water, the solution becomes more acidic and the pH value decreases. Conversely, if the hydrogen ions are consumed in a reaction, the solution will become more basic and the pH value will increase.

Most natural waters have a pH ranging from about 6.0 to about 8.5 (Hem, 1985, p. 64). The range of pH in Indian Wells Valley was from 4.60 (26S/40E-14N1, 06-21-72) to 10.10 (25S/40E-33L1, 03-25-75).

Conductivity

Conductivity is a measure of the ability of a substance to conduct electricity. In water-resource investigations, specific conductance is measured and is defined as the ability of a solution to conduct electricity at a specified temperature and through a unit length and cross section. The standard temperature at which specific conductance is measured is 25°C; the unit length and cross section are 1 centimeter and 1 square centimeter. Specific conductance can be plotted against measured or calculated total dissolved solids (TDS) and a relationship equating specific conductance to TDS can be established (curves are given in Appendix B).

ANALYSES OF ELEMENTS AND COMPOUNDS

Analyses can be obtained for all elements and compounds. A complete analysis of all the possible constituents is not necessary for geochemical investigations. Contributions of many of the elements found in natural waters are small and do not affect the overall quality of the water. Analyzing for a large number of ions can become cost prohibitive.

The major positive ions (cations) that were chosen for the study of water quality in Indian Wells Valley and that most affect the quality of water were calcium (Ca^{++}), sodium (Na^+), magnesium (Mg^{++}), and potassium (K^+). These cations were chosen because they are the most common positive ions contributing to the water quality of the area.

The major negative ions (anions) chosen for water-quality study were chloride (Cl^-), sulfur in the form of sulfate (SO_4^{--}), bicarbonate and carbonate ($HCO_3^- + CO_3^{--}$), and fluoride (F^-). These anions were chosen because they are major contributors to water quality in the valley.

Other elements were included in the analyses because of their effect on humans, livestock, and plants, or because they are geothermal indicators. These elements are silica (SiO_2), boron (B), iron (Fe), and arsenic (As).

Calcium. Calcium is the major cation of the alpine waters. Calcium causes water to be "hard." The low TDS contents keeps the alpine waters "soft." In the evolution of desert waters there is a tendency for waters to change to more sodium-rich waters.

Sodium. Sodium is a very soluble cation. As waters react to the desert environment they tend to become enriched in sodium.

Potassium. Potassium is associated with sodium and behaves in a similar manner. Low sodium-to-potassium ratios may indicate a possible geothermal water.

Magnesium. Although magnesium is generally present in greater amounts than potassium, it is somewhat anomalous to the groundwaters of Indian Wells Valley. The source of magnesium is probably the basalts in the northwest portion of the Valley.

Bicarbonate and Carbonate. Bicarbonate and carbonate are the principal anions contributing to the hardness of water. The carbonate-bicarbonate system is very complex chemically, and variables such as carbon dioxide partial pressure, pH, temperature, type of enclosing rocks, and other ions present affect the system greatly.

Chloride. Chloride is the least reactive of the anions. Many geothermal brines are of the sodium-chloride type.

Sulfate. Sulfate is the least common of the major anions. Four sources of sulfates are in Indian Wells Valley groundwaters: (1) the oxidation of pyrite in Tertiary lake clays, (2) the oxidation of sulfides in mineralized areas, (3) sewage pond leakage (sodium sulfate is added to detergents), and (4) leakage from geothermal steam caps. Another source of sulfate could be sedimentary gypsum or anhydrite beds; however, neither gypsum nor anhydrite has been found in the valley or surrounding mountains.

Fluoride. Although Hem (1985, p. 120) places fluoride as a major element, it is actually a trace element. It is usually lumped with chloride as a major element.

Silica. Silica (SiO_2) is important chiefly as an indicator of geothermal leakage. A discussion of the silica geothermometer is given by Fournier (1981, pp. 113-18).

Boron. Extreme concentrations of boron occur in the surface and shallow groundwaters of China Lake Playa.

Arsenic. Arsenic is of concern because of its toxicity to humans and other animals. Hem (1985, pp. 144-45) gives the Environmental Protection Agency (EPA) standard for drinking water as 50 micrograms per liter ($\mu g/L$). Many analyses of waters from the Indian Wells Valley indicate concentrations of arsenic in excess of 50 milligrams per liter (mg/L). However, Hem (1985, p. 145, citing McKee and Wolf (1963, p. 140)) notes that waters with 1,000 $\mu g/L$ have been used for drinking for short periods of time with no apparent harmful affects but that long term-use of concentrations of 210 $\mu g/L$ was reported to be poisonous.

Berenbrock (1987, p. 40) reports a well (25S/40E-33L1) that on two samplings (05-21-80 and 06-09-82) gave arsenic concentrations of 2,000 and 2,900 $\mu g/L$ respectively.

The mean arsenic content of waters in which arsenic was reported was 152 µg/L. The arsenic concentration frequency distribution is skewed towards high values by a few very high citations, giving a misleadingly high mean. The median or mid value was 15 µg/L. We believe that the median is a more meaningful statistic in this case, in that Valley drinking water that contains arsenic is far closer to the median than the mean.

STUDY TECHNIQUES

SAMPLING TECHNIQUES/INSTRUMENTATION

Sampling techniques were set up to ensure the quality of the on-site measurements and sample preservation. Although the actual sampling routine varied slightly at each site, USGS Water Resources Division procedures were strictly adhered to.

Temperature was measured with an alcohol-based thermometer calibrated against a National Bureau of Standards (NBS)-tested thermometer. The thermometer was rinsed with de-ionized water before and after each use and was dried with lint-free wipes to control contamination.

A Beckman 21 pH meter in conjunction with a Beckman pH electrode and a Corning temperature probe was used to measure pH. The meter was tested immediately before each sample was measured with 4.0-, 7.0- and 10.0-pH standards. Two consecutive readings were taken immediately after the sample was removed from the well or spring, and if the difference between the two was greater than 0.1 unit, then a third reading was taken to resolve the discrepancy. The pH value was recorded on a field sample sheet. Appendix E contains the field sample reporting sheets for this investigation.

A Lab-Line Lectro-MHO-Meter Model MC-1 Mark V conductivity meter in conjunction with Lab-Line Instruments, Inc., conductivity cups was used to measure specific conductance. The meter was standardized each morning before use with three standards bracketing a range from less than 100 microsiemens per centimeter to 2,500 microsiemens per centimeter. The cells were rinsed with de-ionized water a minimum of three times before each use, then rinsed twice with the sample water before being filled for the reading. This procedure ensured that contamination from the previous sample and dilution from the de-ionized water was kept at a minimum.

Three 1-liter polyethylene bottles were filled at each sampling location. The bottles were prepared for sampling as follows. One was filled with filtered water, one was filled with unfiltered water, and one bottle was acidified to preserve certain ions. The non-acidified bottles were rinsed twice with the sample water before filling. Acidified bottles were rinsed with HNO_3 at the lab and the water was filtered through a 0.45-micrometer nitro-cellulose filter with a Geofilter Peristalic Pump. The unfiltered water was taken directly from the spring or well head. Each bottle was labeled, sealed, and cooled for shipment to the laboratory for analysis.

ANALYSIS TECHNIQUES

Laboratory analysis for the samples collected during this study was conducted by ACZ Laboratories, Colorado Springs, Colo.

The best measurement of quality of an analysis is to take the difference of the positive charges on cations and the negative charges on anions, divide that number by the sum of the two charges, and multiply by 100, giving a percent error. A satisfactory analysis should have a percentage error of plus or minus 5%. The positive and the negative charges are given on the laboratory reporting sheets (Appendix E).

Also, when a report of an analysis is received, the investigator should look for obvious or probable errors, and if any results appear erroneous, contact the laboratory and have the analysis checked for typographical errors on the reporting sheet, dilution errors, or other such possibilities.

Table 2 gives the detection limits and analysis techniques for the elements and compounds used in this report.

TABLE 2. Detection Limits (mg/L) and Analysis Techniques
for the Elements and Compounds Used in This Report.

The abbreviations used are USGS: U.S. Geological Survey; EPA: Environmental
Protection Agency; AA: Atomic Absorption; ICP: inductive coupled plasma.

Chemical	Analysis technique	Detection limit, mg/L
Arsenic	USGS (1-2-62-78), AA automated-hydride	0.001
Bicarbonate [a]	EPA 310.1 titrimetric (chemical)	1
Calcium	EPA 200.7 ICP (AA)	1
Carbonate	EPA 310.1 titrimetric	1
Chloride	EPA 32.2 automated ferricyanide	1
Fluoride	EPA 340.3 automated complexone	0.02
Iron	EPA 200.7 ICP	0.02
Magnesium	EPA 200.7 ICP	1
pH	EPA 150.1 meter (units)	1
Potassium	EPA 200.7 ICP	1
Silica	EPA 200.7 ICP	0.1
Boron	EPA 200.7 ICP	0.02
Sodium	EPA 200.7 ICP	1
Solids (dissolved)	EPA 160.1 gravimetric 108°C (precipitation and weighing	2
Sulfate	EPA 375-3 gravimetric	4

[a] As $CaCO_3$.

INTERPRETATION TECHNIQUES

The methods of interpretation for water quality data are many and, as with other types of data, contain many pitfalls. Care must be taken in the collection, preservation, and analysis of the water samples along with the interpretation of the analyses.

The analytical methods used to determine the concentration of the major constituents (solute) in each water sample are reported by the laboratory as the weight (in milligrams) of a given solute per unit volume (liter) of solvent. Minor constituents such as arsenic and boron are reported by the USGS in $\mu g/L$ and by ACZ Laboratories in mg/L.

Water analyses from other sources may be reported in various other units. Conversion factors for these units can be found in Hem (1985).

Chemical Equivalence Between Cations and Anions

To compare different ionic species, a conversion involving the weight and electrical charge of each ion is used. When the formula weight of an ion is divided by the charge of that ion, the result is termed the equivalent weight. If this equivalent weight is then divided into a concentration value reported in milligrams per liter, the result becomes milligram-equivalents per liter. For convenience, milligram-equivalents per liter has been shortened to milliequivalents per liter (meq/L). Table 3 contains the necessary equivalent weights for mg/L to meq/L conversion.

TABLE 3. Conversion Factors for Milliequivalent
Conversions (From Hem, 1985).

Element and reported species	Multiplication factor
Bicarbonate (HCO_3)	0.01639
Calcium (Ca^{++})	0.04990
Carbonate (CO_3^{--})	0.03333
Chloride (Cl^-)	0.02821
Fluoride (F^-)	0.05264
Magnesium (Mg^{++})	0.08229
Potassium (K^+)	0.02558
Sodium (Na^+)	0.04350
Sulfate (SO_4^{--})	0.02082

The following is an example of a conversion for milliequivalents. The analysis is of water from 27S/39E-2161, in mg/L.

Bicarbonate	122
Calcium	41
Carbonate	0
Chloride	17
Fluoride	0.40
Magnesium	0.11
Potassium	8
Sodium	41
Sulfate	49

Calculations:

Cations, mg/L

Calcium	41 x 0.0499	= 2.05
Magnesium	11 x 0.08299	= 0.91
Potassium	8 x 0.02558	= 0.20
Sodium	41 x 0.04350	= 1.78
Total cations		4.91

Anions, mg/L

Bicarbonate	122 x 0.01639	= 2.00
Carbonate	0 x 0.03333	= 0.00
Chloride	17 x 0.02821	= 0.48
Fluoride	0.4 x 0.05264	= 0.02
Sulfate	49 x 0.02082	= 1.02
Total anions		3.52

Percent error $= ((4.91 - 3.52)(4.91 + 3.52)) \times 100 = 16.29\%$

The use of milliequivalents per liter denotes that the unit concentration of all ions are chemically equivalent, i.e., that for each unit of positive ion (cation) there is one unit of negative ion (anion). In a stable environment, the balance of cations and anions should equal zero.

This chemical equivalence between cations and anions provides a quick yet reliable method of evaluating the quality of both the sampling technique and the laboratory analysis. If one assumes that the environment the sample was taken from was in equilibrium, then a comparison of the computed milliequivalents per liter for the major cations (Na, K, Ca, and Mg) versus the major anions (Cl, SO_4, F, CO_3, and HCO_3) will enable a balance to be made, and if no balance exists, to show the degree of error present.

Hem (1985) states that "Under optimum conditions, the analytical results for major constituents of water have an accuracy of plus or minus 2 to plus or minus 10%." Balances have been computed for all of the analyses used in this report.

Stiff Diagrams

Graphical representation of milliequivalents per liter allows the user a visual means of comparing gross water composition without the need for tables of data.

A modified "pattern" diagram, similar to the one described by Stiff (1951) was chosen to aid in the classification and analysis of water types in Indian Wells Valley. This pattern, commonly called a modified Stiff diagram, reduces the effects of dilution or concentration on the shape of the pattern and facilitates the interpretation of sample analyses.

The modified Stiff diagrams are based on a meq/L comparison of the major cations and anions of a given sample. The cation and anion equivalents are plotted to the left and to the right of a vertical axis, respectively. The horizontal scale is in meq/L, and similar species such as sodium and potassium are grouped and labeled as such (Na + K, Cl + F, HCO3 + CO3). Graphically displayed comparisons of the chemical constituents dissolved in natural waters are an easy way to compare the gross chemical composition of waters.

After the points have been plotted on the graph, they are then joined together by straight lines forming a closed diagram. This closed pattern is the modified Stiff diagram. Modified Stiff diagrams can be calculated by hand or be computer derived. The diagrams in this report were computer derived. One of the main values of Stiff and modified Stiff diagrams is they are visually recognizable "fingerprints" for major groundwater types.

As the composition of the dissolved constituents contained in a water sample change over time, the shape of the modified Stiff diagram will change. Plotting the diagrams on a map in their respective sampling positions will show spatial variability in the gross water composition, while a temporal comparison will show changes in composition over time.

GROSS WATER CLASSIFICATION BY MAJOR IONS

Another method of classifying water is by gross composition. This method also uses the meq/L values but compares the percentage of the major cations and anions and classifies the water based on the percentages of each constituent. If a certain cation or anion makes up over 20% of the total cations or anions, that ion is included in the naming of a water. The cation with the largest percentage of the total cations is named first in the water type, then the cation with the second largest percentage, with the naming continuing until the percentage of the remaining largest cation drops below 20%. The anions are next, with the largest percentage leading. The anions also continue to be named in lesser percentages until the percentage of the remaining largest anion also drops below 20%. This listing of cations by lessening percentage followed by anions by lessening percentage makes up the water-type name. For example, a water could be of a sodium-chloride (Na-Cl) type, a sodium-calcium-chloride (Na-Ca-Cl) type, or a sodium-calcium-magnesium-chloride-bicarbonate-sulfate (Na-Ca-Mg-Cl-HCO3-SO4) type.

CONDUCTIVITY VERSUS TOTAL DISSOLVED SOLIDS

Estimates of TDS (mg/L) in a water sample can be obtained by using specific conductance, eliminating the need to send the sample to a laboratory. Specific conductance measures the ability of the sample to conduct electricity at a specific temperature and through a unit distance. Plotting calculated TDS against specific conductance allows the establishment of a curve relating one variable to the other. If specific conductance for a particular water type is measured and compared against an established relational graph of specific conductance versus TDS, then the TDS content for the sample can be estimated.

An attempt was made to correlate specific conductance with TDS using water analyses from the USGS records and those samples collected specifically for this study. Many of the USGS analyses did not include both TDS and specific conductance. Both of these parameters are necessary to construct the relational curve mentioned above. Because so few analyses were complete, graphs for all water types and areas were not reliable. However, relationships for TDS versus conductivity for specific water types were calculated.

Using a computed TDS (sum of major components measured in mg/L) and conductivity, a linear regression line was fitted to the data. A correlation coefficient "R" was computed for the line. If R = -1.00 or +1.00, there is a perfect correlation between the independent and dependent variables. If R = O, there is no correlation. Using the data from all analyses, R = 0.30, which is unsatisfactory. We decided to attempt correlation again using the computer-derived water types. Curve fitting was attempted only if there were three or more samples of a water type (two samples always give a straight line with perfect correlation). In general, linear regression lines fit well. The resulting curves of computed TDS versus conductivity are shown in Appendix B. By determining the water type (by the method described in the next section) and by taking the conductivity of a sample, you can determine the TDS using the appropriate curve.

DETERMINATION OF GROUNDWATER
FLOW SYSTEM CELLS

Figure 3 is a plot of areas where various types of groundwater are found, areas described as groundwater flow system cells. This map was prepared from three sets of data, all maps.

In the first map, waters that gave similar modified Stiff diagrams were plotted, and areas where a given water type dominated were outlined on a map of the Indian Wells Valley (Naval Weapons Center map, 1982).

In the second map, computer-generated water types were plotted using color codes for each ion in the classification. In general, this map and the first map were in good agreement.

A Utah State computer agency made contour maps of the analyses for sulfate, boron, pH, and TDS. In general these maps confirmed the assignment of areas made on the basis of the above methods.

a. Overall map.
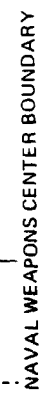
FIGURE 3. Water Types at the Naval Weapons Center and in the
Indian Wells Valley.
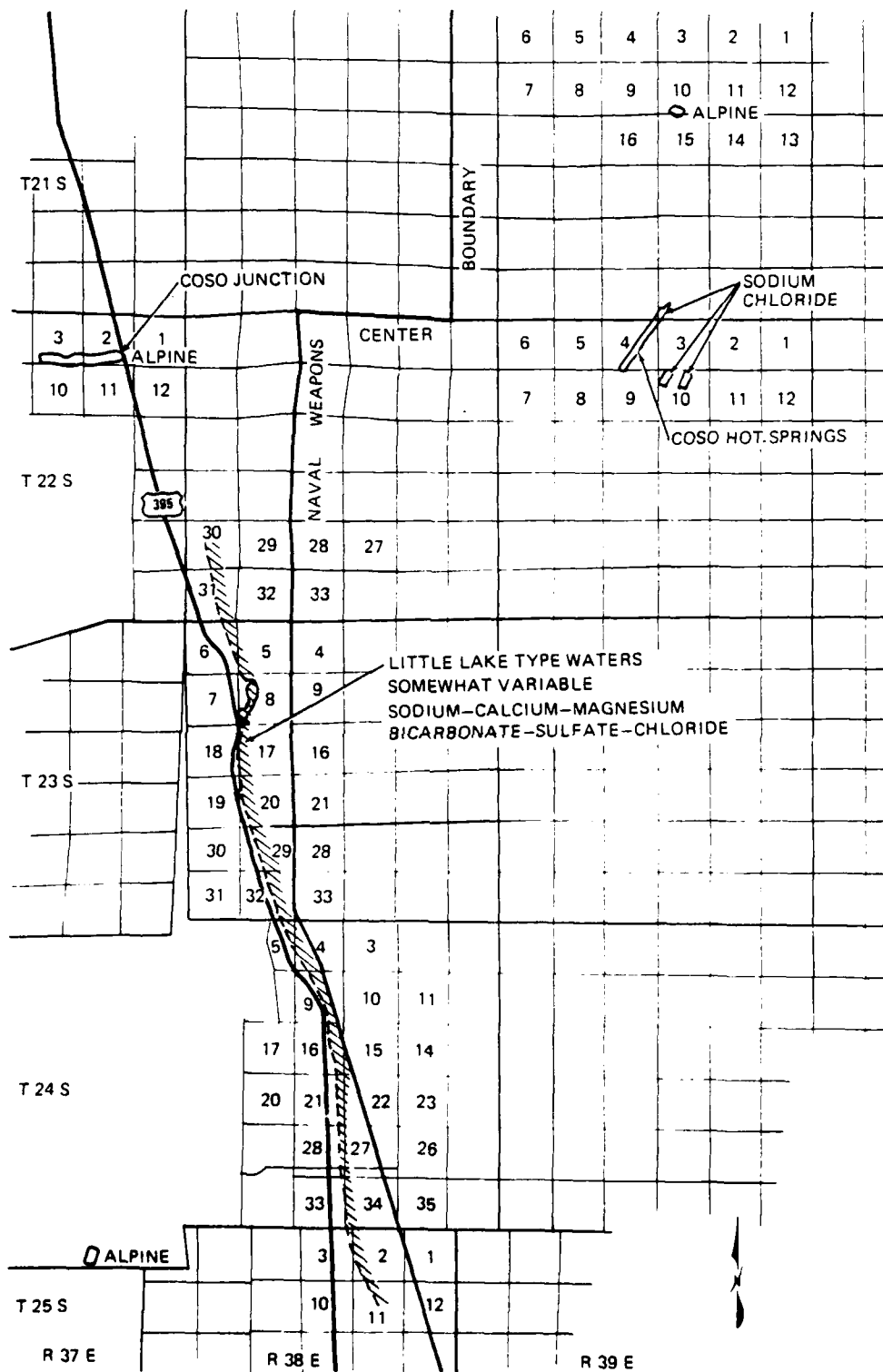
b. Detail 1.

FIGURE 3. (Contd.)
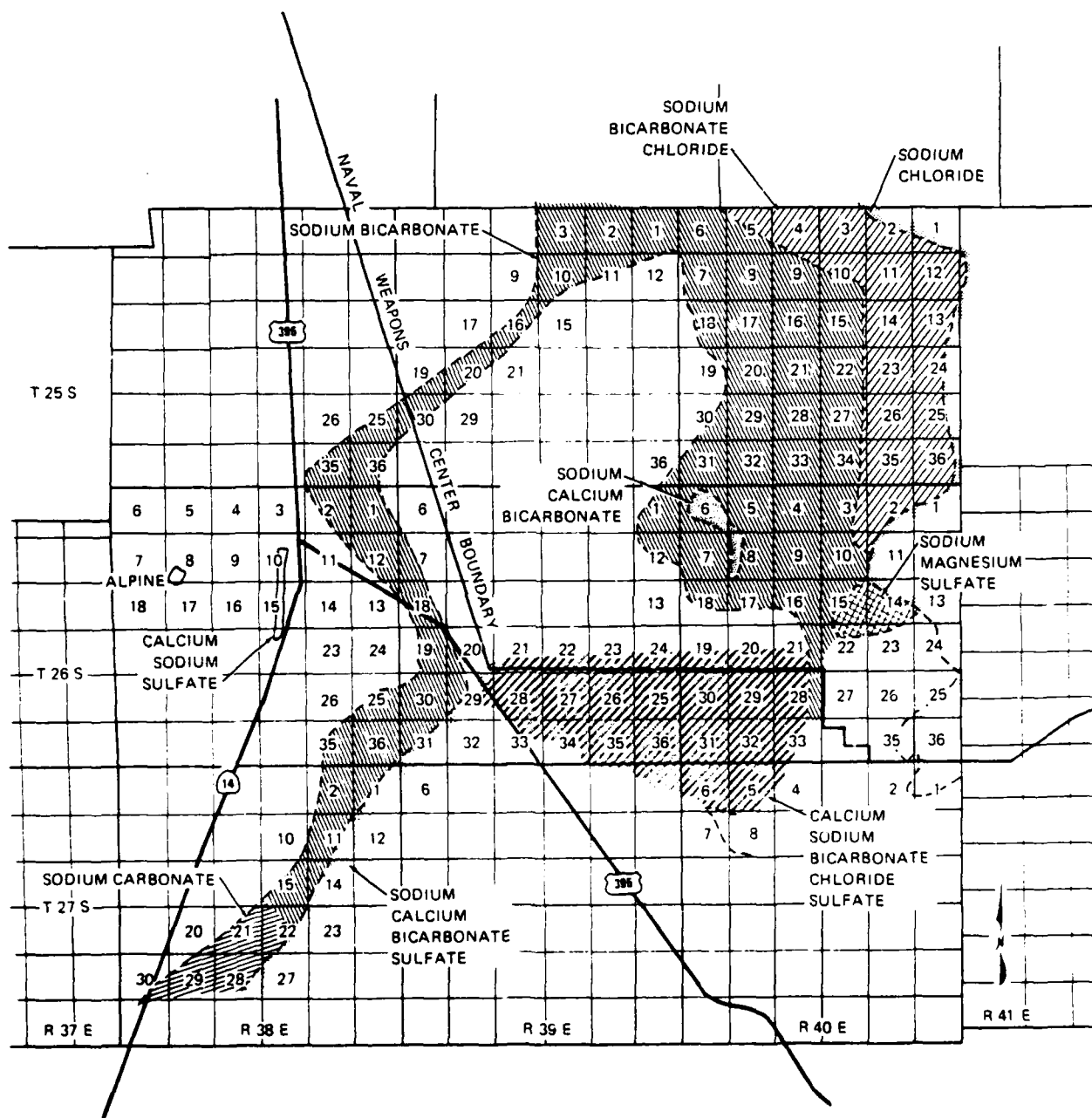
c. Detail 2.

FIGURE 3. (Contd.)
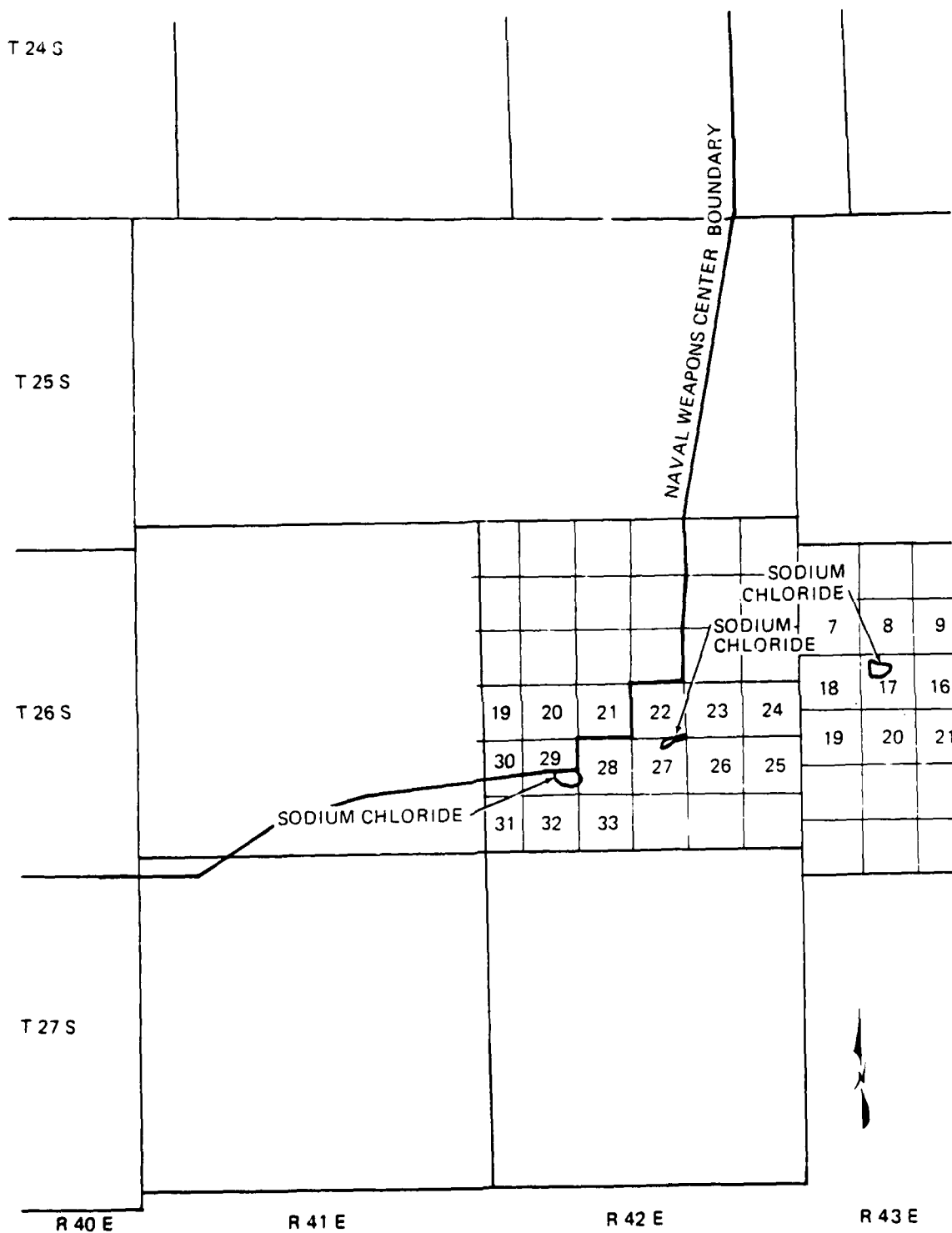
d. Detail 3.

FIGURE 3. (Contd.)

We wanted to determine what kind of rocks the various types of water had been in contact with. Doing so would allow us to identify "bedrock" inflows. Dr. T. Cerling, Assistant Professor of Geology, University of Utah, noted that one of his students in 1985 had considerable success relating the rocks of a drainage basin to water chemistry using a trilinear plot of silica, alkalinity, and sulfate plus chloride.[*] The scheme was developed by Stallard and Edmond (1983). To use it, one computes the milliequivalent of the silicon, alkalinity (bicarbonate plus carbonate), and chloride plus sulfate, and sums them. The individual milliequivalents and the sum are used to compute percentages for their plotting.

Stallard and Edmond's study was of the Amazon Basin. We were doubtful that the scheme would work in the Mojave Desert because of the great difference in climatic conditions, which affects rock weathering. Also, the scheme was developed for surface waters, not groundwater. Pederson's study was in the bighorn basin of Wyoming. All analyses with the appropriate components analyzed were calculated and plotted (Figure 4). As one would expect, most sample sites were in a plutonic and volcanic area because of the proximity of the Sierra and Coso volcanics. Some sites were plotted in the limestone area, shale area, evaporate (playa) area, and geothermal area. The geothermal area was added to the plot by Whelan (Figure 4). Trends of water types as determined by the scheme were plotted on another copy of the referenced map. The trends were in general agreement with the trends of water types as determined by the other methods.

Unfortunately, the fact that some waters appear to have a limestone affinity and others have a shale affinity does not prove or disprove the presence of Paleozoic metasediments in the basement. The Indian Wells Valley has been occupied by Holocene and Pleistocene lakes, which affects the results significantly. Stallard and Edmond (1983) also proposed a trilinear plot of milliequivalent of alkalinity, calcium plus magnesium, and sulfate recalculated to 100% to relate water compositions to the sedimentary rock environment. All applicable water analyses were plotted on this diagram (Figure 5). It appears that this diagram, developed for surface waters in the tropics, is not applicable to the groundwater environment of the desert in Indian Wells Valley as the majority of the points show a sedimentary relationship (Figure 4). Because much of the alluvium is composed of Sierran Rocks, which are granitic with lesser metamorphic rocks, one would expect the waters to have exhibited an igneous association.

Figure 3 is considered the most important product of this investigation. However, one must be cautioned on its use because of certain limitations. Dashed lines are used to separate water types. They are dashed because in general the boundaries are very approximate, this because of the lack of sufficient data points in large areas. When wells of moderate depth produce reasonable amounts of water, of good quality, many wells are drilled. Where the aquifer is very deep, the yield poor, or the quality poor, few wells are drilled and control for plotting deteriorates.

Another factor is depth control. Of 375 wells sampled through the years by the USGS, total depths are available for only 150, or 42%. Of the sites sampled specifically for this study, depths were available for 7 of 12 wells, or only 58%. Only rarely were depths of the aquifer available. Very few deep wells are in this Valley. In the China Lake Playa, for instance, only very shallow wells were available for sampling; therefore, any freshwater underflows were ignored.

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[*] Pederson, B. L. 1985. Geochemical Studies in the Bighorn Basin, Wyoming. Unpublished Master's Thesis, University of Utah, pp. 37-45.
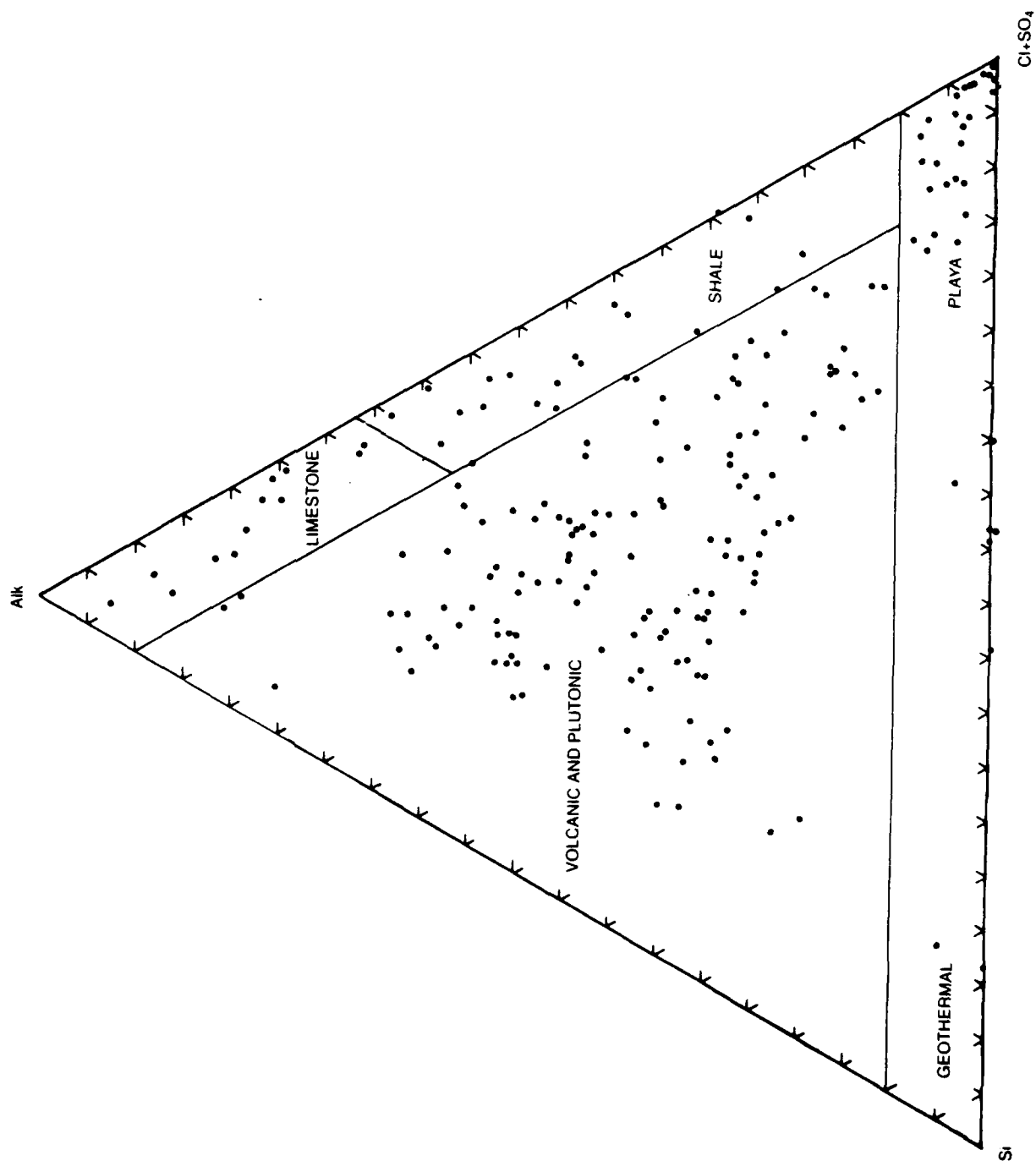
FIGURE 4. Triangular Plot of Water Types in the Indian Wells Valley and Other Areas.
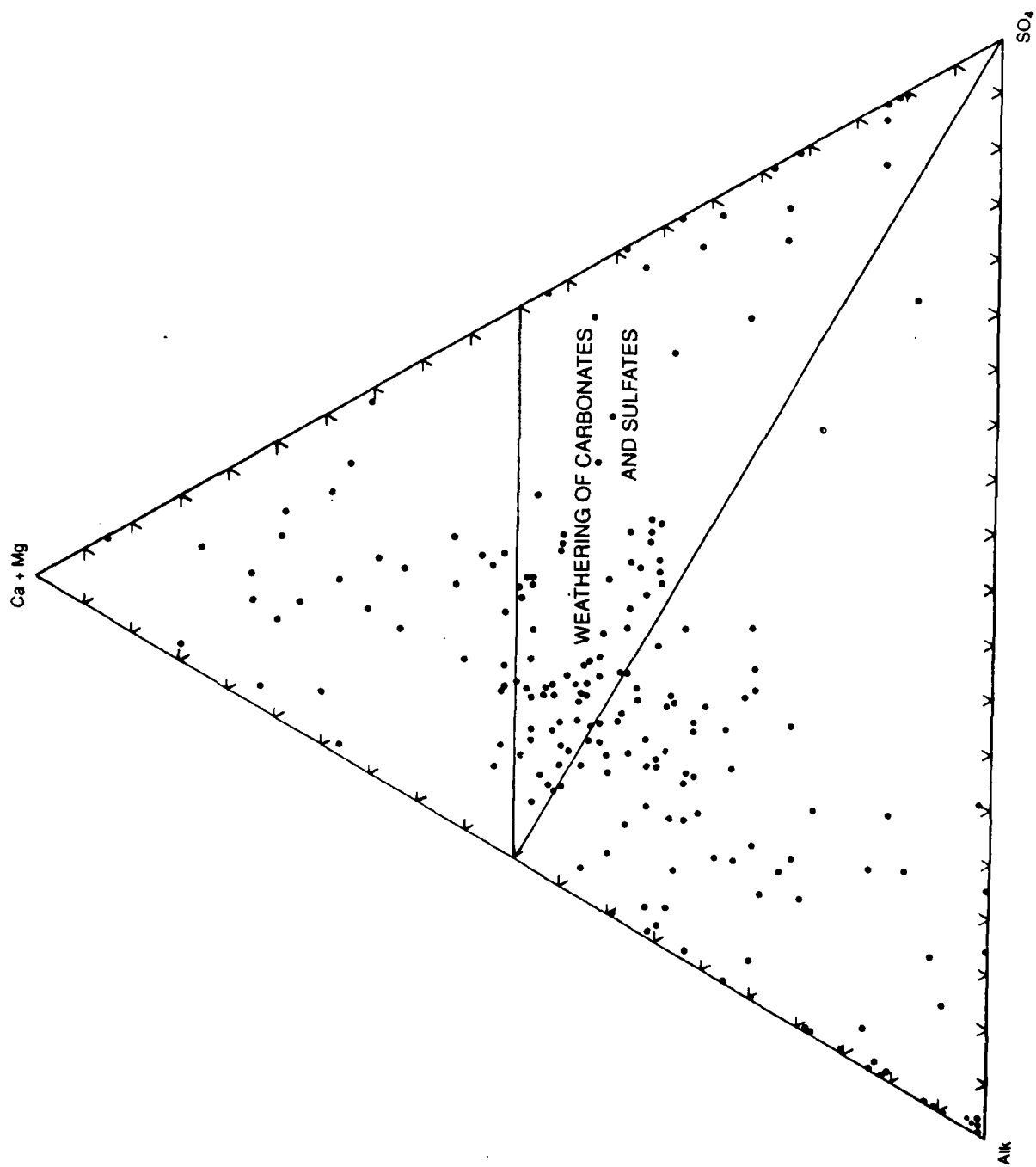
FIGURE 5. Weathering of Carbonates and Sulfates.

Figure 3 contains some personal interpretation. For instance, sodium-calcium-chloride and calcium-sodium-chloride waters were lumped together in areas of mixing. If one well had a different water type than most others in an area or was much different in depth compared to the others, it was not used.

We acknowledge that Figure 3 is a preliminary map but believe that it will be useful in subsequent investigations. We expect that future workers will improve upon it.

THRUSTING AND LISTRIC FAULTING COULD PROVIDE MAJOR WATER COLLECTORS

The growing realization of probable thrusting with associated listric faulting in the Sierra, the Coso Range, and the Argus Range has many implications on interpretation of the groundwater geochemistry. The hanging wall of a thrust sheet would probably be an aquitard—a barrier to groundwater flow. The footwall is probably badly sheared. The crushed footwall of a thrust in the Oquirrh Mountains or Utah is known to the operating geologists of the Bingham Canyon Copper Mine as the "chaotic area." Thus the footwall of a thrust could well be a major aquifer, while listric faults and dish-shaped thrusts could serve as major water collectors in the hanging wall system (Silver, 1986). Fracture permeability can be very high. As examples, in driving the San Jacinto tunnel in granites, flows of up to 16,200 gpm occurred when major faults were crossed (Procter, White, and Terzoghi, 1946), and a geothermal well (54-3) in the Roosevelt Geothermal Field near Milford, Utah, producing from the dome fault zone with a diameter of just over 9 inches, had an initial mass flow of 1,500,000 pounds of steam and water per hour (approximately 3,000 gpm).* Thus water could be entering the Indian Wells Valley from beneath thrust plates of the Sierra.

Another aspect of possible thrusting in this region is that the lower plates are believed to be sediments.** Also, the basement under Indian Wells Valley could be sediments. Mifflin (1968) shows that there are large interbasin flows of groundwater under mountain ranges in Nevada. The Naval Weapons Center Rocketeer (18 March 1988) noted that springs at the Onyx Mine in the Panamint Valley can produce 60,000 gallons of water per day or 70 acre-feet per year. These springs may be an example of interbasin underflow beneath the ranges. It is highly probable that there is interbasin leakage from Indian Wells Valley through the Poison Canyon area and under the Argus Range as a whole into Searles Valley, and south through the Paleozoics of the El Paso Mountains into Freemont Valley.

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* R. Lenzir, personal communication with Dr. J. A. Whelan, 1976.
** M. Erskine, personal communication with Dr. J. A. Whelan, 1988.

WATER TYPES

WATER TYPES DEFINED BY THIS STUDY

Alpine Waters

The least-modified water in the region would be meteoric water derived from the granitic terrain of the Sierra. These waters are of the calcium-magnesium-sodium-bicarbonate-sulfate-chloride type (Figure 6). These waters are normally of low TDS. As these waters work their way to the Valley they are modified by evapotranspiration, reactions with soils and rocks, and mixing with other waters.

Na+K ┐ ┌ Cl+F

Mg   SO4

Ca   HCO3+CO3

5   -5
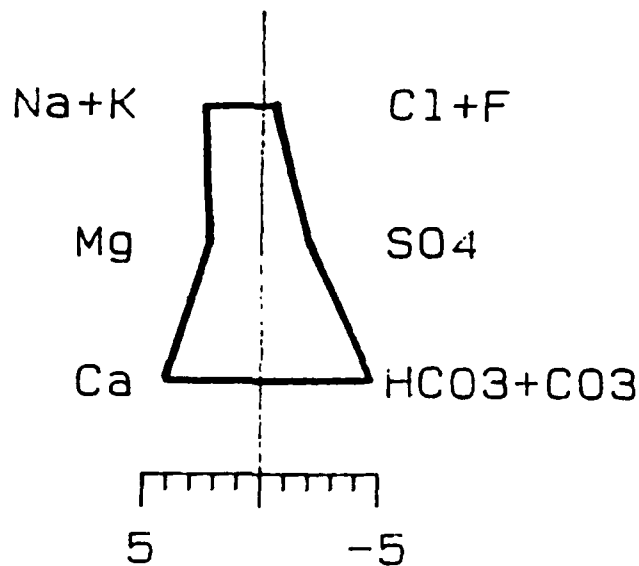
FIGURE 6. Grumpy Bear Well in 22S/36E-21.

Sodium-Chloride Waters

Two sources of sodium-chloride brines are in the Indian Wells Valley region: geothermal brines and playa brines.

The analyses of a typical geothermal brine (Coso Geothermal Exploration Hole (CGEH)-1, Coso Geothermal Field) given by Fournier and Thompson (1980) together with an analysis of a sodium-chloride playa brine are given in Table 4. Salt Wells and Searles Lake waters are also of this type. A modified Stiff diagram is shown in Figure 7.

TABLE 4. Analyses of Sodium-Chloride Type Brines.

Item	CGEH-1, sampled at approximately 360 ft	China Lake, 253140E 25H1 (USGS data)
Temperature	195°C	...
pH	5.40	7.3
SiO_2	119	...
Ca	55	26
Mg	1	71
Na	1,510	26,000
K	132	320
Li	13	...
HCO_3	119	570
SO_4	53	130
Cl	2,330	40,000
F	3.3	...
B	49	912
Calculated TDS	4,384.43	...
TDS measured	...	66,400
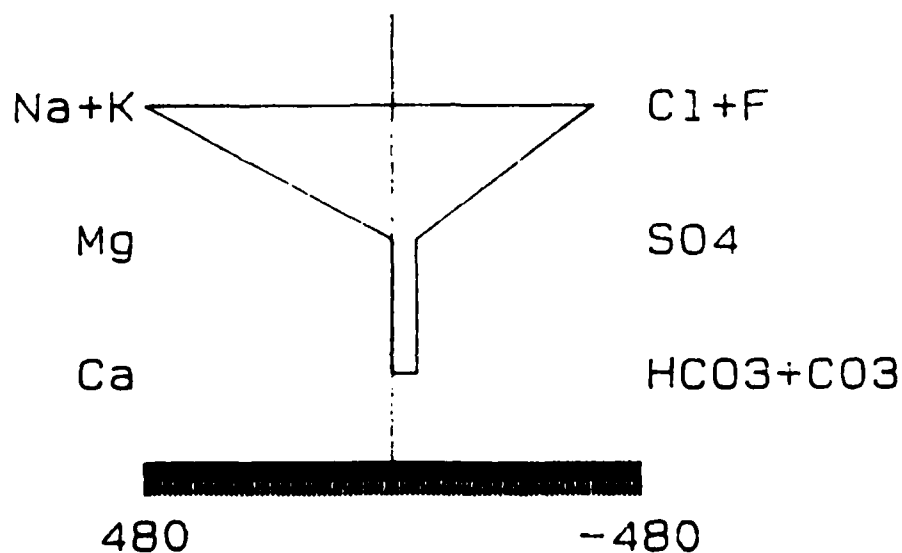
FIGURE 7. Sodium-Chloride Waters.

Sodium-Carbonate and Sodium-Bicarbonate Waters

The location of these waters is shown in Figure 3. Most are sodium-bicarbonate waters. Of special interest are waters from 27S/37E-31B and 26S/35E-35L. These are sodium-carbonate waters with low TDS. A similar water is present in the 103-foot well by the old house at the south end of the Coso Hot Springs area. This is not to imply that there is any communication between these areas, but to note that there may be an inflow of geothermal waters into the southwest corner of the Indian Wells Valley. It is our experience that sodium-carbonate and sodium-bicarbonate geothermal waters generally indicate low-temperature systems. A modified Stiff diagram of these waters is shown in Figure 8.

Sulfate Waters

There are several occurrences of sulfate waters in the area. One is Walker Well, a calcium-sulfate-bicarbonate type water. A sulfide-type mineralization exists near Walker Well.

Waters from the Tungsten Peak Mine (Figure 9) and a shallow well at 38E/26S-15Q are of the calcium-sodium-sulfate type. It is believed that the sulfate is from sulfides found in contact metamorphic mineralization (minerals formed where an igneous rock has intruded a sedimentary rock). When the mine was in operation, it made 110 gallons per minute or about 180 acre feet per year.
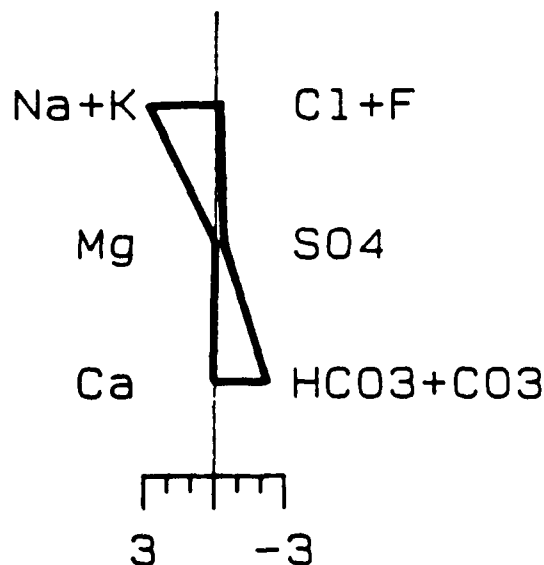
FIGURE 8. Sodium-Carbonate and Sodium-Bicarbonate Waters.
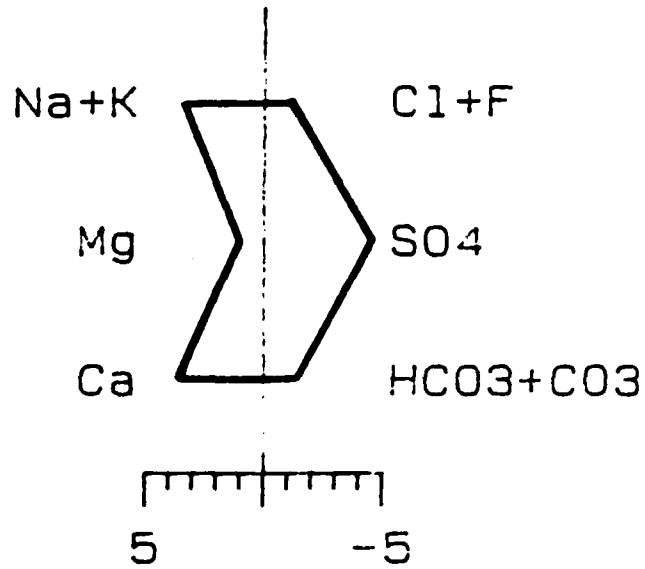
FIGURE 9. Tungsten Peak Mine in 26S/38E-10H, on 9-16-86.
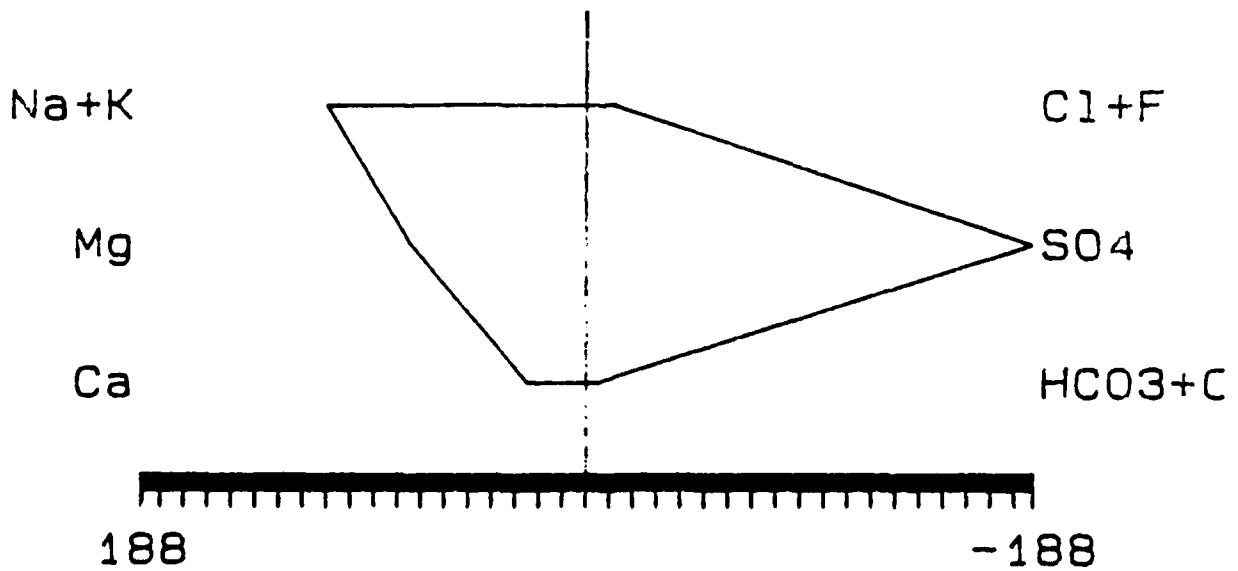
FIGURE 10. "Sewage Water," in 26S/40E-22H2, on 6-8-82.

A shallow seepage from the sewage ponds is a very peculiar sodium-magnesium-sulfate water (sodium sulfate has replaced phosphates in detergents (Figure 10)).

Red Hill/Little Lake/Lumber Mill Waters

A complex but interesting set of waters is called Red Hill/Little Lake/Lumber Mill waters. These waters are found in sampling sites from east of Red Hill in Rose Valley to the area where Brown Road turns from north to west at the site of the former village of Brown in Indian Wells Valley. The waters are of somewhat varying types. The exploration hole at Red Hill was of the sodium-calcium-bicarbonate type. Well 22S/38E-8C is of the sodium-calcium-magnesium-bicarbonate type; Little Lake Spring is a calcium-bicarbonate-chloride type. The Lumber Mill site is of the sodium-bicarbonate-chloride-sulfate type, and a well in 39E/25S-11P is a sodium-bicarbonate-chloride-sulfate water. However, the modified Stiff diagrams indicate that the waters are of all of one family. The various cations and anions (except bicarbonate, which dominates the anions) hover around 20% of the milliequivalents, so they drop in and out of the computer classification. A modified Stiff diagram of the Little Lake Spring is shown as Figure 11.

Mixing models did not work well on Little Lake/Lumber Mill site waters. We believe that the calcium and bicarbonate ions are a contribution from alpine waters. The sodium is probably geothermal, and that the magnesium is probably leached from the basalts. We believe very strongly that the chloride represents a Coso geothermal component. The sulfate is more difficult to evaluate. Its source could be geothermal (Coso) or deep Rose Valley waters. Isotope data confirm the presence of a geothermal component in the northwestern Indian Wells Valley.

GROUNDWATERS OF THE INYOKERN INTERMEDIATE AND RIDGECREST WELL FIELDS

The groundwaters of the Inyokern intermediate and Ridgecrest well fields are complex waters. Electrically, sodium is usually the dominant cation, although calcium occasionally is. Magnesium contents are low. Bicarbonate is almost always the dominant anion. Chloride is usually the next dominant anion. Sulfate may or may not be present in amounts large enough to appear in the computer classification.

Only order of magnitude results can be determined by mixing models because of reactions of groundwaters with enclosing rocks (solution of mineral, deposition of minerals, ion exchange), transpiration (loss of water from plants), evaporation, and mixing of two or more waters with or without chemical reactions. In using mixing models chloride is often weighted heavily because it is the ion least reactive to surrounding rocks. It appears that the waters of the Inyokern well field could result from the concentration of alpine waters by evaporation and transpiration and mixing with a few percent geothermal brines. The intermediate field would have less geothermal leakage or other sodium-chloride water leakage. To create the waters of the Ridgecrest field would require a larger geothermal component than to create the usual waters of the intermediate field, but a smaller geothermal component than to create the waters of the Inyokern field.
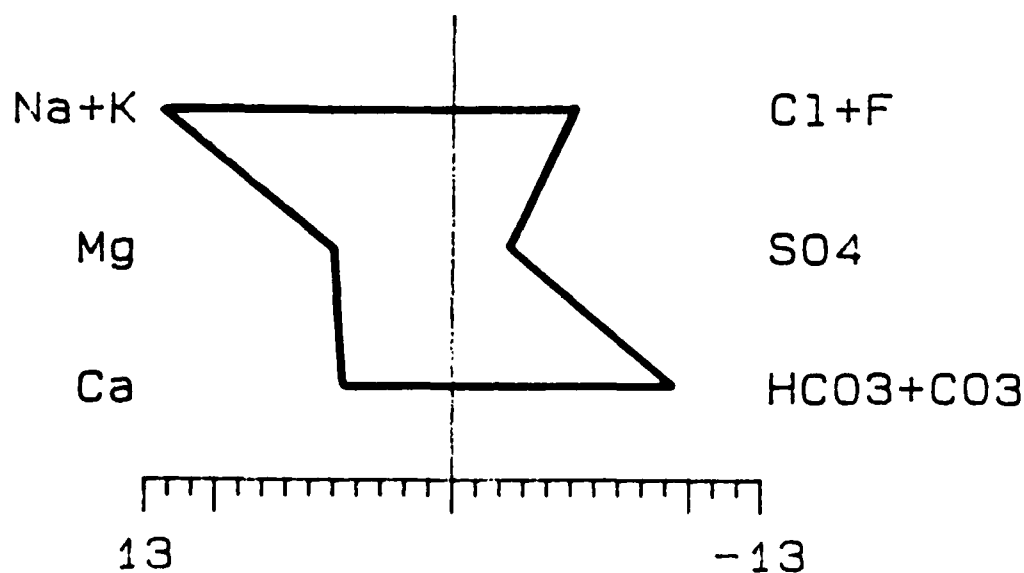
FIGURE 11. Little Lake Spring, in 23S/28E-17, on 9-18-86.

WATER TYPES ACCORDING TO TOWNSHIP

Refer to Figure 3 for location of the townships discussed here.

Township 22 South, Range 37 East (T22S/R37E). Chemical analyses of groundwater samples from wells and springs in T22S/R37E along the Sierra front and at Coso Junction reveal those waters to be similar to groundwater typically found on the crest of the Sierra Nevada, located west of Indian Wells Valley. T22S/R37E includes the southern part of Rose Valley and a portion of the east slope of the Sierra range. All of the analyses used from this section came from within Rose Valley itself. This area was included in the study because of its close proximity to Indian Wells Valley and previous studies that suggest water movement from Rose Valley into Indian Wells Valley through the Little Lake area. The shallow waters found in Rose Valley are typically a calcium-sodium-magnesium-bicarbonate type based on the 20% water classification scheme and are a result of direct recharge from the Sierra to the west.

Waters from the Rose Valley Ranch house well and irrigation well to the north of Coso Junction are of the calcium-sodium-sulfate-bicarbonate-chloride type. The house well is 675 feet deep and the irrigation well 724 feet deep. The irrigation well is capable of producing 2,000 gpm without measurable drawdown.[*]

Township 22 South, Range 38 East (T22S/R38E). Only one water sample was obtained from T22S/R38E. This sample was taken from an exploration drill hole just east of Red Hill (22S/38E-30K1) and is very similar to water from the Little Lake sampling sites. The TDS content of the water from this well was 875 mg/L, and the water was a sodium-calcium-bicarbonate type. The water taken from the Red Hill site had a high silica content (82 mg/L) implying some connection with geothermal activity.

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[*] Phil Hennis, personal communication with Dr. J. A. Whelan, 1979.

Township 22 South, Range 39 East (T22S/R39E). T22S/R39E includes the Coso Geothermal Field in the northwest and part of the Coso Range to the southeast, and contains a wide range of water types. The array of differences between the waters can be attributed to geothermal activity, various drilling depths, and structural differences throughout the area. The principal geothermal brine is of the sodium-chloride type with about 5,000 mg/L TDS. This area is located to the immediate north of Indian Wells Valley and may be affecting the quality of water in Indian Wells Valley itself via both Coso Valley and Coso Basin. There is some evidence that geothermal waters are entering Indian Wells Valley in the area around Little Lake and the basalt flows. Two observation holes have been drilled in Section 10 (22S/39E-10D1 and 10C1). The waters encountered in these holes are mixtures of sodium-chloride type geothermal brines and valley underflow, which is similar to the alpine waters of Haiwee spring at the head of the valley to the north (21S/39E-10P). The westernmost well water is about 90% geothermal leakage and 10% valley underflow, the well to the east is 60% geothermal water and 40% underflow. The holes are a quarter of a mile apart. The amounts were calculated by a chloride mixing model and checked with mixing models of the other major ions.

Township 23 South, Range 38 East (T23S/R38E). The water samples that were collected from T23S/R38E-8C, Little Lake Spring, and the well at the site of the lumber mill (now removed) include the well in 8C, which is 150 feet deep. All are complex multi-cation and anion waters that we have designated the Red Hill/Little Lake/Lumber Mill multi-cation type.

The northwest corner of Indian Wells Valley lies in T23S/R38E and includes the areas both north and south of the Little Lake surface-water divide. Groundwaters north and south of the divide are very similar in composition with only a slight increase in TDS to the south. Pumping records from the lumber mill at the bottom of Nine Mile Canyon show virtually no drawdown over the past years even though over 1,000 acre feet of water have been removed from the area annually. The recharge rate to the area affected by the pumping must logically be equal to the amount of water being removed from the aquifer by that pumping. Water from the area of the lumber mill is high in TDS and appears to be affected by contributions from geothermal waters. Water to the west of the lumber mill site, towards the alpine waters, quality can be expected to improve as one leaves the lower valley fill and moves up gradient towards the mountains.

Township 23 South, Range 39 East (T23S/R39E). T23S/R39E lies towards the center of NWC and includes Airport Lake and, in its southwest corner, part of the basalt flows. No water samples have been analyzed from this area. However, because this township lies directly south of the Coso Geothermal Field there is a strong possibility that any groundwater found in this area will contain a significant geothermal component.

Township 23 South, Range 40 East (T23S/R40E). T23S/R40E lies east-northeast of Airport Lake and down gradient from Mountain Springs Canyon and Renegade Canyon. This township is also located within the NWC boundary. No water analyses from the township have been performed.

Township 23 South, Range 41 East (T23S/R41E). The Mountain Springs Canyon area in the Argus Range lies within T23S/R41E and is located to the northeast of Indian Wells Valley. This township includes Mountain Springs Canyon waters, several of which have been analyzed. The water of the spring itself is of the calcium-sodium-magnesium-bicarbonate-chloride type. Water from the Wild Rose Mine is of the calcium-sodium-magnesium-bicarbonate type.

Township 24 South, Range 38 East (T24S/R38E). T24S/R38E lies directly south of the township containing the Little Lake divide and rests along the Sierra on the western side of Indian Wells Valley. In the northeast and eastern sections of the township, the waters are of the Red Hill/Little Lake/Lumber Mill area type. In the southwest corner of the township the water quality is similar to an alpine type water.

Township 24 South, Range 39 East (T24S/R39E). T24S/R39E is located northwest of China Lake Playa and south of the Coso Geothermal Field and includes the southeast section of the basalt flow and a portion of the White Hills. The chemical composition of the waters in this area are mainly sodium-bicarbonate. Waters from this area have a high TDS content. Drilling has been limited in this area because of the quality of water encountered and the location of the township within the confines of NWC. It is possible that the water from this township has been affected by inflow from the geothermal area; however, there is insufficient data to evaluate this idea.

Township 24 South, Range 40 East (T24S/R40E). T24S/R40E includes the southeast portion of the White Hills and Paxton Ranch to the southeast. The township lies entirely within the confines of NWC and contains only a few scattered wells. The township seems to be an area of water mixing with many complex types—sodium-chloride-bicarbonate (6A1, White Hills), sodium-magnesium-calcium-chloride (20J1), calcium-sodium-chloride (24E1), and sodium-calcium-magnesium-chloride (36 M1, Paxton Ranch).

Township 24 South, Range 41 East (T24S/R41E). T24S/R41E includes part of the Argus Range on the east side of Indian Wells Valley. Fournier (1979) sampled a spring in Wilson Canyon (section 13F). The water is of the calcium-magnesium-bicarbonate type.

Township 25 South, Range 38 East (T25S/R38E). T25S/R38E is located along the western edge of Indian Wells Valley and includes the area northwest of Leliter. Water types vary both with depth and location within this township. Water from wells in sections 13, 14, 23, and 24 are similar to waters from the Los Angeles aqueduct. The waters differ slightly from alpine waters by an increase in magnesium and a decrease in calcium. However, the changes are minor, and positive differentiation of water type between alpine and aqueduct waters is very difficult, if not impossible. These alpine waters probably represent recharge from the Sierra Nevada.

Sand Canyon surface water was sampled from a short stretch of stream in section 7 on 21 August 1986. This water was an alpine type water. Because the chemical composition of water may change drastically upon removal from the ground, this sample was not used in the overall investigation of water quality in Indian Wells Valley. However, the stream was reabsorbed into the ground just below the sampling site, thus providing recharge to the groundwater system in the valley.

A water sample from a deep well in the northeast corner of the township (section 11) has the characteristics of Red Hill/Little Lake/Lumber Mill type water. Although this well lies in the middle of the aforementioned alpine water plume, the deep well probably samples from a lower aquifer influenced by the higher-density Red Hill/Little Lake/Lumber Mill type water. This sampling site was the furthest southern extent of the pure Red Hill/Little Lake/Lumber Mill type water signature.

In section 36 of this township, samples were collected from one well at different depths. There was an overall increase in TDS and a great increase in sulfate with depth. There are no data from the SW corner of this section.

Township 25 South, Range 39 East (T25S/R39E). T25S/R39E is located towards the center of Indian Wells Valley and lies northeast of Leliter. This township lies almost entirely within the confines of NWC and contains a few scattered wells. Many of the wells were sampled in 1946 with no recent samples taken (Bailey, 1946). There seems to be both Little Lake type waters and alpine waters in this township. Because of limited depth data, it is not possible to interpret the groundwater system in this township.

Township 25 South, Range 40 East (T25S/R40E). T25S/R40E lies to the north of Armitage Field, includes much of China Lake Playa, and is located entirely within the boundaries of NWC. Depth control for this section is also very poor, yet there appears to be a specific pattern in the quality of the water within this township. The south and southeast edges of the township contain water of a distinctly higher TDS and are of a sodium-chloride or sodium-bicarbonate type. The western part of the section appears to be influenced by alpine type waters. Yearly samples from a well in section 20, from 1974-1976 (depth 174 feet), show an alpine type water. Water from section 18 also is strongly influenced by alpine water. Perhaps water is coming from the west and forming a plume into this section.

Township 25 South, Range 41 East (T25S/R41E). T25S/R41E includes portions of the Argus Range and the southeast section of China Lake Playa. There are few samples from this township and all of them are from the China Lake Playa area. This water is a sodium-chloride type with high TDS and is probably directly related to evaporation near and in the playa area.

Township 26 South, Range 38 East (T26S/R38E). T26S/R38E lies to the southwest of Leliter and contains water samples from a well located in 15Q, the Tungsten Peak Mine (formerly the Hi-Peak Mine), Indian Wells Canyon, and sites further east in the valley alluvium.

Water from the northern half of the township is primarily a sodium-calcium-sulfate water. This water type extends all the way across the township and into the next township to the east. The water-sample collection from the Tungsten Peak Mine came from the third level from a pipe driven into the bedrock in that area. The wells to the south and east of this area are probably getting some recharge from the bedrock.

A deep well in section 27 (723 feet), which was sampled in 1974, had a TDS content of approximately 300 mg/L, a field pH of 6.3, and a sample temperature of 29.5°C. The high temperature and abnormally low pH indicate that this water may have been affected by geothermal activity.

Another indication of geothermal activity in the area comes from a well in the southeast corner of the township. This well had a TDS of less than 200 mg/L, a field temperature of 27.5°C, and a pH of 9.36. The water is of the sodium-carbonate type. Alpine water lies to the west in section 33.

Township 26 South, Range 39 East (T26S/R39E). T26S/R39E includes the town of Inyokern and the western end of Inyokern Road. Sections 23 and 24 display two distinct water bodies above and below an indicated break line around 300 to 350 feet. Perhaps this is a separating clay layer. In sections 29 and 30 the water bodies are basically

all the same. The waters from the shallower wells are calcium-sodium-bicarbonate-sulfate-chloride waters, while waters from the deeper wells are of the sodium-bicarbonate type.

Township 26 South, Range 40 East (T26S/R40E). T26S/R40E encompasses the communities of China Lake and Ridgecrest, the eastern half of Inyokern Road, and Armitage Field. Samples from this township indicate the presence of two aquifers. The shallow aquifer, generally less than 50 feet, has been sampled extensively throughout the area and contains over 40 years of records. In the last 10 years or so, there has been an overall increase in TDS. This increase seems to be related both spatially and chemically to direct seepage from the sewage-treatment ponds located in sections 13, 14, and 14a, and to using sewage effluent to water the NWC golf course in sections 23 and 24. A limited amount of data is available on the deep aquifer (generally greater than 500 feet), but the water quality seems to be relatively constant over time except in the case of one deep well. The two aquifers are probably separated by a structural control, such as a clay layer, that prohibits or inhibits movement of water between the aquifers.

An influx of sodium-sulfate water causes the water quality of the shallow aquifer to vary greatly. The spatial relationship between the sewage ponds and the contaminant plume and the fact that the sewage effluent is sodium-sulfate water points to the sewage lagoons and the watering of the golf course as the principal contributors to the increase in TDS in the very shallow aquifer. This plume of contaminated water runs NE to SW and can be seen most dramatically on the sulfate contour map generated by computer.

A limited amount of data is available for the deep aquifer in this area; however, it appears that the quality of water has not changed significantly over time.

Water samples obtained from the north and northeast sections of the township, in the vicinity of China Lake Playa, show an increase in sodium-chloride content probably because of the proximity of China Lake.

Township 26 South, Range 41 East (T26S/R41E). T26S/R41E lies to the east of China Lake and includes Lone Butte and Salt Wells Valley. Water samples from this township are of a high-TDS, sodium-chloride type and are not suitable for domestic or irrigation use. These waters are very similar to those found just to the northwest of the township in the China Lake playa area and to waters pumped from the Leslie Salt Company wells located in 26S/43E-17D.

Township 27 South, Range 38 East (T27S/R38E). T27S/R38E lies in the southwest corner of Indian Wells Valley and includes Freeman Junction and Armistead. Few wells are located in this township, but those with water quality analysis in the western Sierran portion indicate that the water is of the alpine type. Water from section 31D is of the sodium-carbonate type with a TDS of 196 mg/L and a fluoride content of 4.6 mg/L. These characteristics could represent condensate from a geothermal system.

Township 27 South, Range 39 East (T27S/R39E). T27S/R39E is located just north of the El Paso Mountains. Many of the wells in 27S/40E have waters of the sodium-chloride type although there are wells with other types of water (such as well 27S/40E-1D, which has sodium-chloride-bicarbonate water with 452 mg/L TDS). Both of these types of water could represent geothermal leakage. The second type could be a mixture of a sodium-chloride and a sodium-sulfate geothermal brine. Haystack Peak, to the east, exhibits snowmelt. That is, after a light to moderate snow, Haystack Peak will be snow free while the surrounding areas are snow covered. This phenomenon is an indication of geothermal leakage. Well-defined snowmelt areas occur at Coso and Roosevelt

Geothermal Fields. (Roosevelt is near Milford, Utah.) The waters of 27S/41E may be leakage from the Haystack system entering the township over clay layers in the alluvium.

CHANGES OF WATER QUALITY

CHANGES WITH DEPTH

Water quality is a relative term. What is good quality depends upon the use. What would be excellent culinary (drinking, domestic use) water would indeed be poor quality water for the producer of salt. High-quality water in a hot-water-type geothermal reservoir would have a high temperature and low TDS. Feed water for the boilers should have low TDS. However, most people consider water quality in terms of culinary waters, irrigation water, and water for livestock. For these purposes, the gross measure of quality is TDS, but certain trace elements, such as arsenic in culinary water or boron in irrigation water, are also important. Hem (1985, pp. 210-15) cites EPA standards for culinary waters and gives a good discussion of water quality in relation to use including industrial uses. In this section of this report, water quality is referred to in the gross sense—amount of TDS.

Water quality may increase, decrease, or remain constant with depth. Some examples of water quality increasing slightly with depth include the Red Hill/Little Lake/Lumber Mill waters. The spring at Little Lake has a TDS content of 1,084 mg/L, while the Lumber Mill site well with a depth of 611 feet has water with a TDS of 1,228 mg/L. A deep well just inside the NWC boundary (26S/39E-21N) near the Inyokern substation had a dissolved solids content of only 215 mg/L (residue at 180°C) and calculated TDS of 221 mg/L. Figure 12 shows the dissolved solids content of this deep but very pure water and the shallower wells around it. Figures 13 and 14 show variations of water quality in some wells of varying depth within specific sections.

CHANGES WITH TIME

There are two schools of thought on the groundwater system of the Indian Wells Valley. One school, whose strongest proponent is Dr. Pierre St. Amand (1986), holds that the groundwater system is a closed basin and that losses from it are limited to consumptive use, evapotranspiration, and evaporation from China Lake Playa. By making the assumption that the values of the losses at the playa equals the recharge, one can then present strong arguments that the users of water in Indian Wells Valley are "mining" water and that the future of the Valley is indeed quite bleak.

The second school, whose most vocal proponent is Dr. C. F. Austin, acknowledges the surficial losses given above but makes considerably different assumptions on subsurface recharge and losses. He believes that the groundwater system is open, that recharge exceeds the surface losses, and that Indian Wells Valley is actually contributing water to both Searles Valley to the east through the underflow beneath the Argus Range and to the Koehn Lake/Cantil area to the south through underflow beneath the El Paso Mountains and Black Hills.
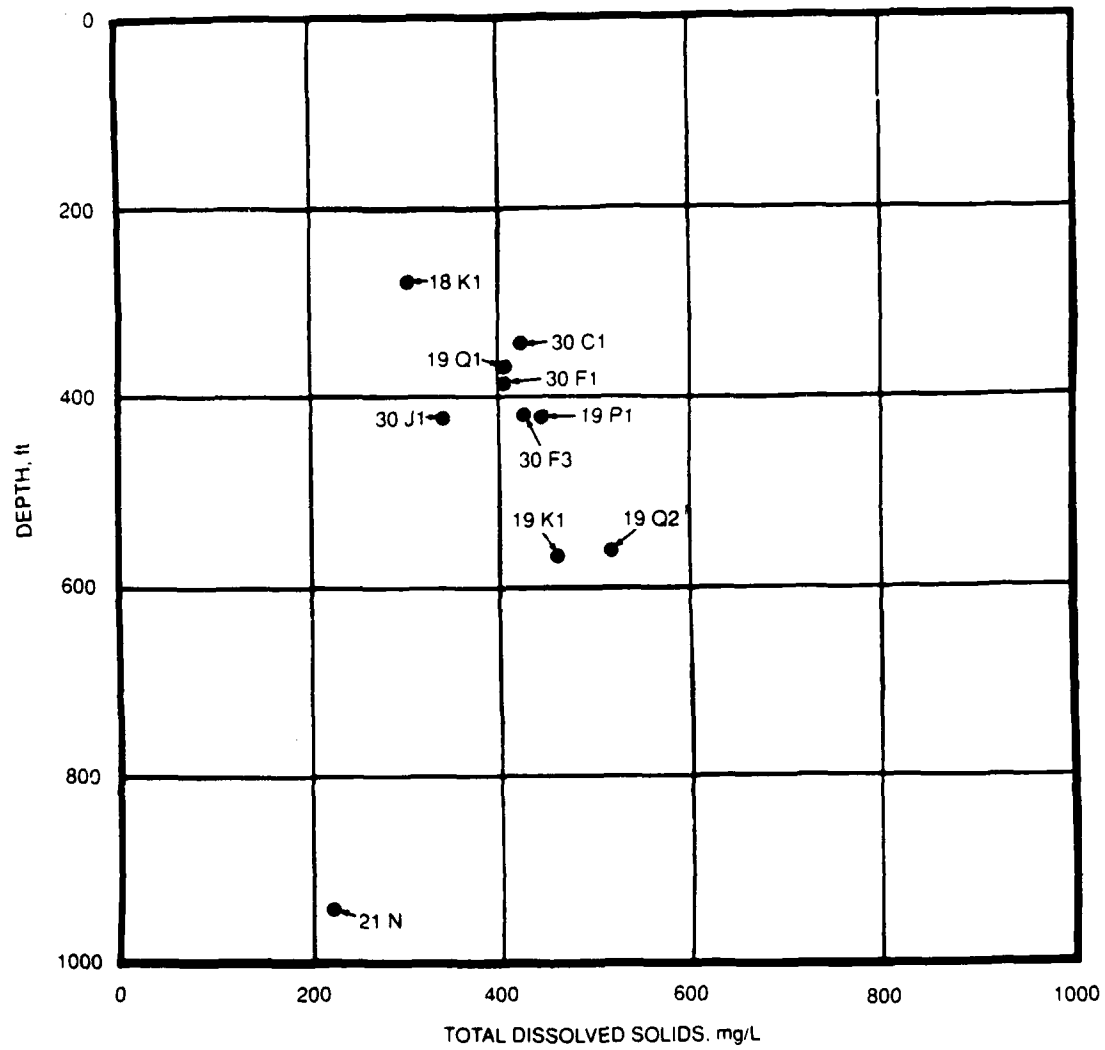
FIGURE 12. TDS at Well 26S/39E-21N and Closest Surrounding Wells.
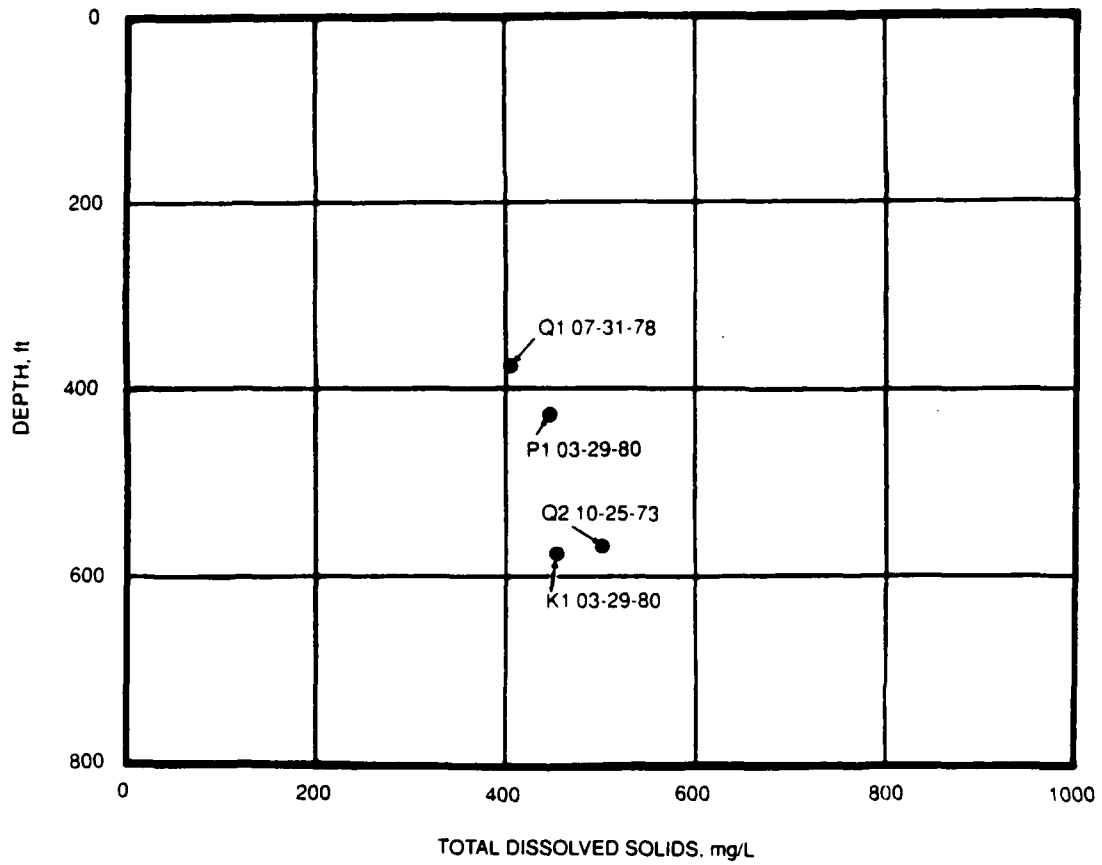
FIGURE 13. TDS Versus Depth in Wells in 26S/39E-19.
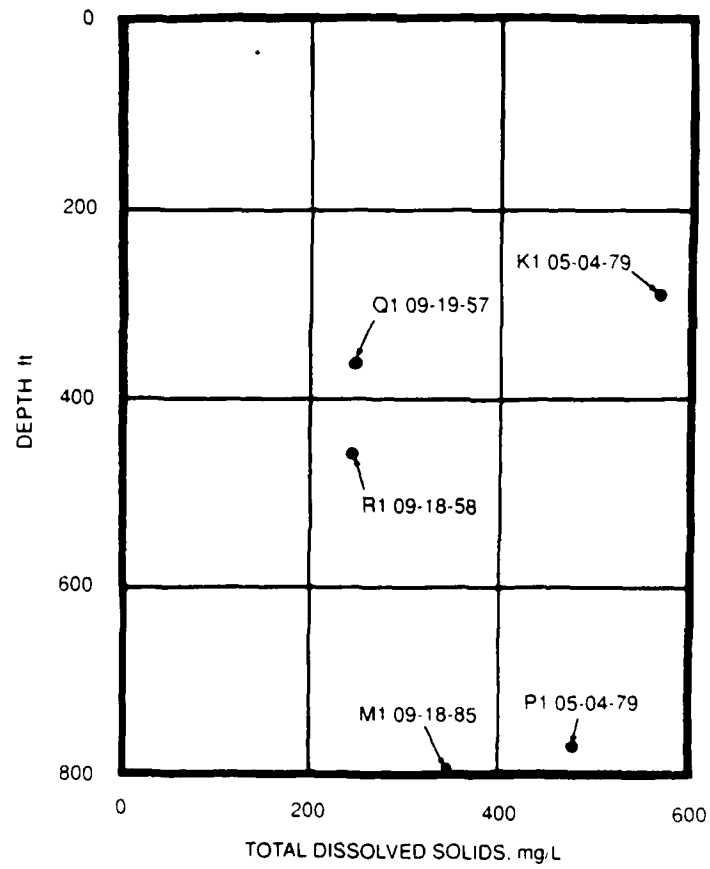
a. Section 26S/39E-24.

FIGURE 14. TDS Versus Depth in Wells in the Sections Noted.
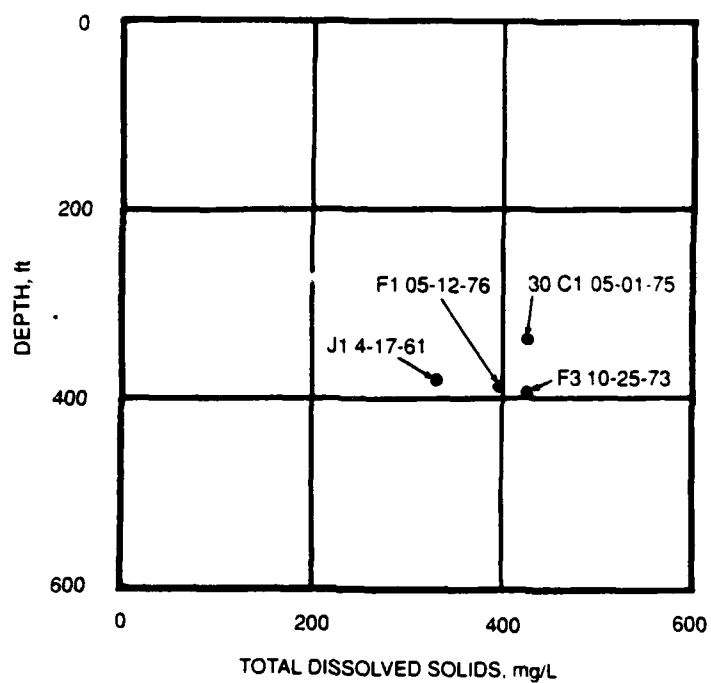
b. Section 26S/39E-30.

FIGURE 14. (Contd.)
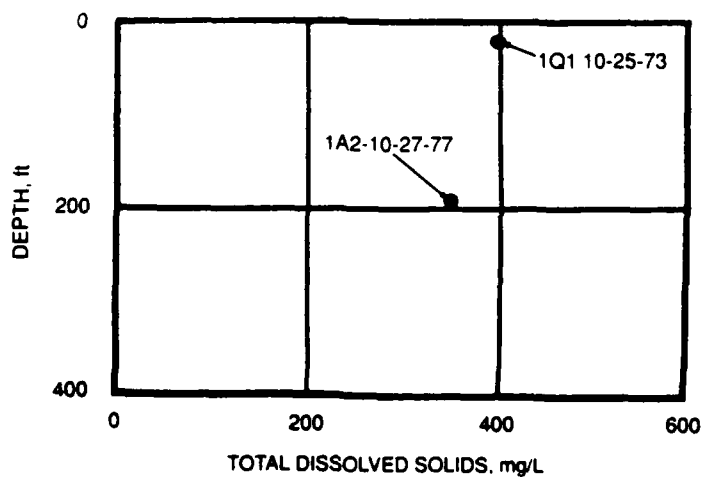
c. Section 24S/40E-01.

FIGURE 14. (Contd.)

Our evaluation of what geochemical data contributes to the solution of the above dilemma, both factual and hypothetical, will be given in the Summary.

The closed-basin school is very concerned that high usage will cause significant lateral migration of water from areas of possibly poor water quality, hence degrading waters where deep pumping depressions occur. Of special concern is the possible migration of sodium-chloride waters into the Ridgecrest well field from the southern and southeastern parts of the city.

In 1975, Warner stated "in 1972 the dissolved solids concentration in the groundwater in some areas is increasing slightly, but where this has occurred, it is not yet serious."

In 1987, the USGS made a proposal for funding to the Indian Wells Valley Cooperator Meeting on the basis of water-level decline and water-quality degradation. They documented their proposal with five graphs.

We had computer printouts made of the various ion concentrations of all sample sites used by the USGS with serial print outs. We tried to estimate changes of quality with time visually, but this approach did not prove satisfactory.

The approach finally taken was to convert the time intervals to days and to calculate TDS by summing the major components—those with concentrations reported in mg/L, not μg/L. There is considerable scatter, probably because of normal variance of analyses, slight variation in the components, mistakes in analyses or reporting. Regression lines (best-fitting lines mathematically) were then calculated for the data. If the fit was good (goodness-of-fit can be calculated) and if the slope is positive, the quality of water was decreasing; if negative, increasing (which is doubtful); and if zero, remaining constant. This approach was partially successful; the times when it was not are attributable to poor curve fits because of the scatter noted above.

Except for a few wells in the Ridgecrest area, and the shallow waters of "area R" on NWC being contaminated by seepage from the sewage ponds, we believe that the quality of water in the Indian Wells Valley is changing little, if any, at most wells.

GEOTHERMOMETERS

The Geothermal Program Office at NWC is the Navy's lead laboratory for geothermal exploration. The Program Office has long believed that the Indian Wells Valley contained a low- to moderate-temperature geothermal resource that could be tapped for space-heating purposes. Indirect evidence for a resource within the Valley was seen in elevated water temperatures pumped from wells, old hot springs deposits, and unusual snowmelt patterns. Now, however, a more direct method of determining geothermal resources is available by the use of chemical geothermometry. Chemical geothermometry uses water analysis results in estimating the geothermal reservoir location and temperatures. The two main families of chemical geothermometers are the silica geothermometers and the alkali geothermometers.

Silica Geothermometers

Several silica chemical geothermometers are available: quartz-conductive-cooling (also called quartz-no-steam-loss), quartz-steam-flashing (also called quartz-maximum-steam-loss), chalcedony-conductive-cooling, alpha-cristobalite, ß-cristobalite, and amorphous silica (Fournier, 1981). All silica geothermometers use the general formula

$$T = [x/(y - \log A)] - 273.15$$

where

T = the reservoir temperature (°C)
x = a number from 784 to 1309, depending on the type of silica geothermometer
y = a number from 4.51 to 5.75, depending on the type of silica geothermometer
A = the concentration of SiO_2 in parts per million (or mg/L)

During the course of this study, all the silica geothermometers were calculated from available water analyses. Our experience with the alpha-cristobalite, ß-cristobalite, and amorphous silica geothermometers indicate that they sometimes give unsatisfactory results; in this study they gave numerous temperatures below freezing. These results are therefore not reported. Results for the quartz-conductive-cooling, quartz-steam-flashing, and chalcedony-conductive-cooling are given in Appendix A.

Waters derived from geothermal resources are enriched in dissolved silica. Therefore, excluding mistakes in analysis, all sample collection errors tend to lower calculated results; for example, precipitation of silica after sample collection but before analysis and dilution of geothermal waters by cold, low-silica waters. Hence, silica geothermometers represent minimum resource temperatures. Also, the silica geothermometers generally apply in the temperature range of 0 to 250°C (Fournier, 1981). Above 250°C, the quartz solubility curves depart drastically from experimental curves, making reasonable calculated temperatures impossible. Because all silica geothermometers have the same type formula, the general form of contoured results should be the same. Therefore, only the quartz-conductive-cooling geothermometer was contoured (Figure 15).

The highest temperatures calculated in the Indian Wells Valley with the quartz-conductive-cooling geothermometer are east of Armitage Field at NWC and exceed 140°C. These higher temperatures are part of a larger area of warm calculated temperatures (>120°C) trended north-northeast that cuts between the mainside area of NWC and the airfield. The most striking feature on Figure 15 is the plume of colder water (<40°C) emerging in the vicinity of the intermediate wellfield. This plume spreads out and appears to trend north-northwest, paralleling the hotter water to the southwest. One other area of cold water (<60°C) is seen along the eastern boundary of the map, just east of the area of highest temperatures.
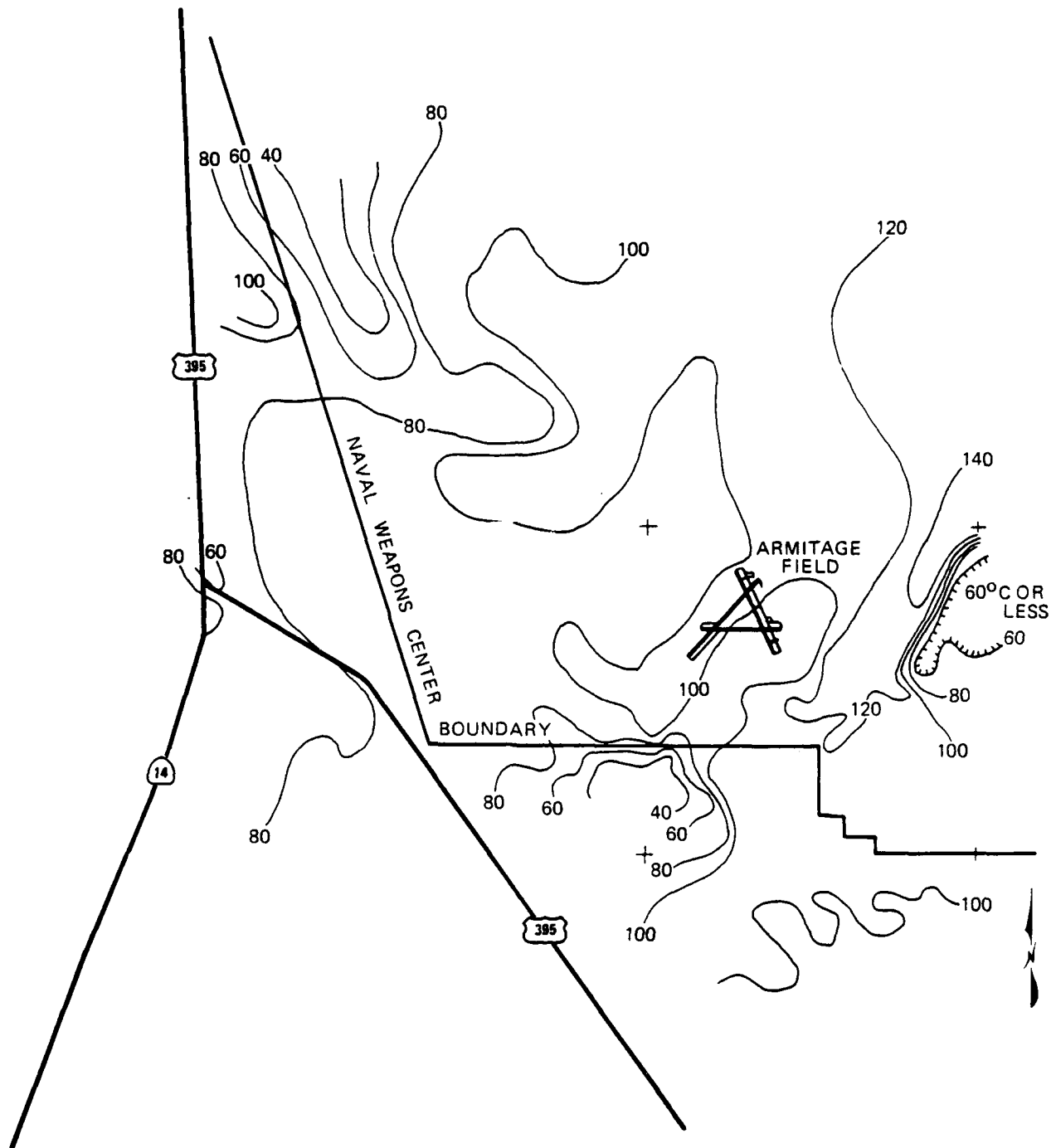
FIGURE 15. Temperature Contour Lines as Calculated
From the Quartz-Conductive-Cooling Geothermometer.

Alkali Geothermometers

The most commonly used alkali geothermometer is the sodium-potassium (Na-K) type. Truesdell (1976) initially developed the Na-K geothermometer, which was later modified by Fournier (1979). Where waters come from high-temperature environments (>180 to 220°C) the Na-K geothermometer generally gives excellent results. The main advantage of the Na-K geothermometer is that it is less affected by dilution and steam separation than other commonly used geothermometers, provided that there are few positive ions of sodium or potassium (Na^+ or K^+) in the diluting waters relative to the reservoir water. It appears, however, that the Na-K method generally fails to give reliable results for waters from environments below 100°C. In particular, low-temperature waters rich in calcium give anomalous results by the Na-K method (Fournier, 1981).

The sodium-potassium-calcium (Na-K-Ca) geothermometer of Fournier and Truesdell (1973) was developed specifically to address calcium-rich waters that give anomalously high calculated temperatures by the Na-K method (Fournier, 1981). The effect of dilution on the Na-K-Ca geothermometer is generally negligible if the high-temperature geothermal water is much more saline than the diluting water and the geothermal water contains more than 20 to 30% geothermal brine. Fournier and Potter (1979) showed that the Na-K-Ca geothermometer gives anomalously high results when applied to waters rich in the magnesium ion. To address this problem they devised a magnesium correction, which is applied when appropriate.

The Na-K, Na-K-Ca, and the Na-K-Ca-Mg calculated reservoir temperatures are given in Appendix A. The Na-K-Ca values are contoured in Figure 16.

The Na-K-Ca geothermometers indicate a high temperature (>200°C) anomaly just south of Armitage Field (Figure 16). This anomaly trends west-northwest with smaller spurs from it trending southwest. Other small anomalies of >200°C temperatures lie to the northwest, north, and northeast of this main anomaly, although the anomalies to the northwest and northeast could be extensions of the main anomaly. There is a large moderate-temperature (>140°C) anomaly emerging north of Armitage Field trending north-northwest completely across the Indian Wells Valley. However, this anomaly is based on only a few data points and will need more data control to characterize. Areas of cooler waters (<100°C) are seen northeast of the airfield (two anomalies), and along the eastern boundary of the study area, immediately east of the airfield.

Discussion

Comparison of the quartz-conductive-cooling and the Na-K-Ca geothermometers (Figures 15 and 16 respectively) show few similarities. The greatest similarity is in the area of cooler waters located along the eastern boundary just east of the airfield. However, just west of this lies the north-northeast trending high-temperature anomaly, which is seen clearly by the silica geothermometer, but only as a spur from a larger anomaly by the alkali geothermometer.

We think that this area is a prime target for further geothermal exploration because of its proximity to large Navy laboratories. Space-heating costs can be dramatically cut in these buildings if a moderate-temperature resource exists. Toward this end, three thermal-gradient drill sites have been located within these anomalies (Figure 17) with drilling of two of the wells expected to conclude before January 1990. Results of this drilling will provide the next step in the exploration process for geothermal resources within the Indian Wells Valley.
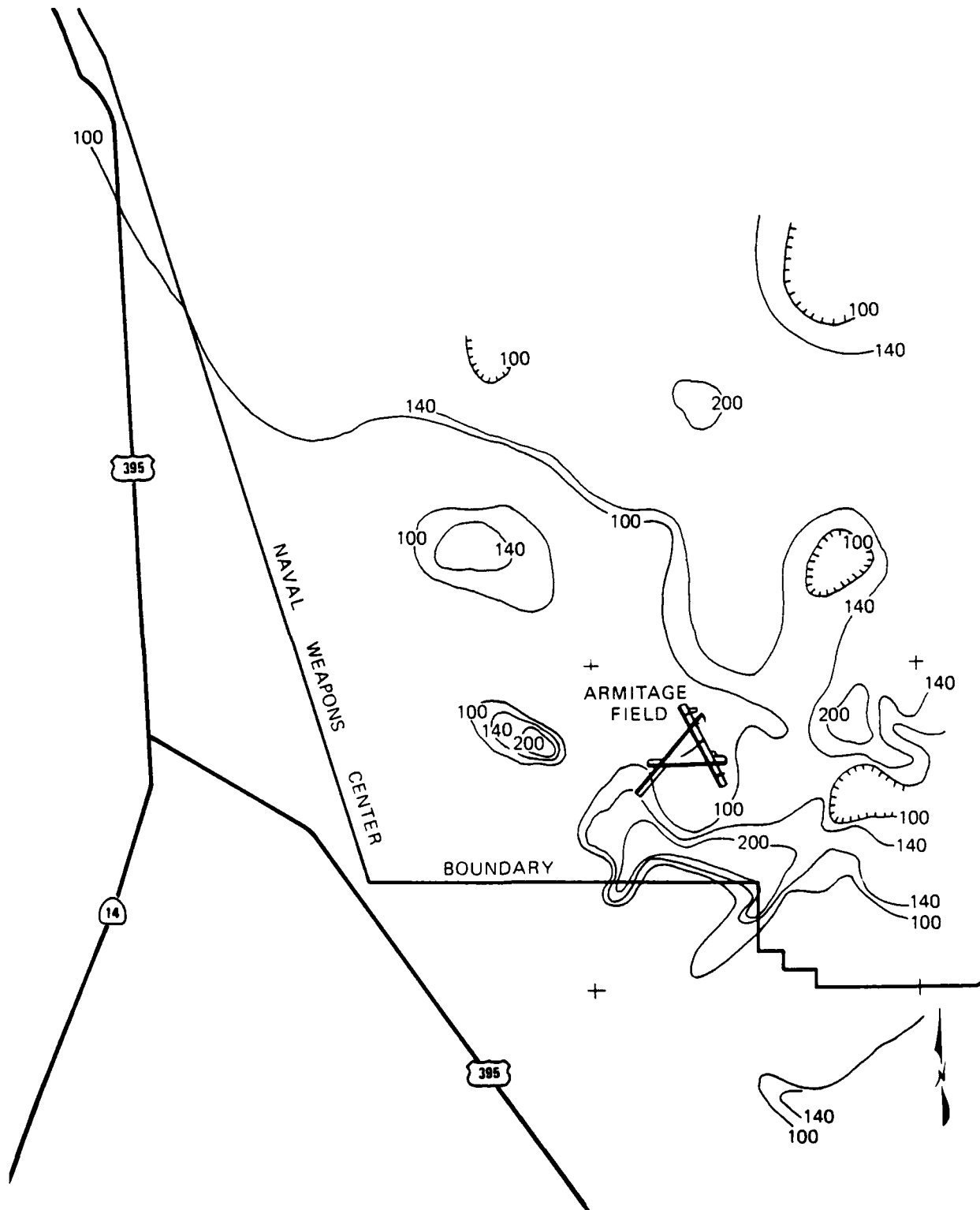
FIGURE 16. Temperature Contour Lines as Calculated
From the Na-K-Ca Geothermometer.

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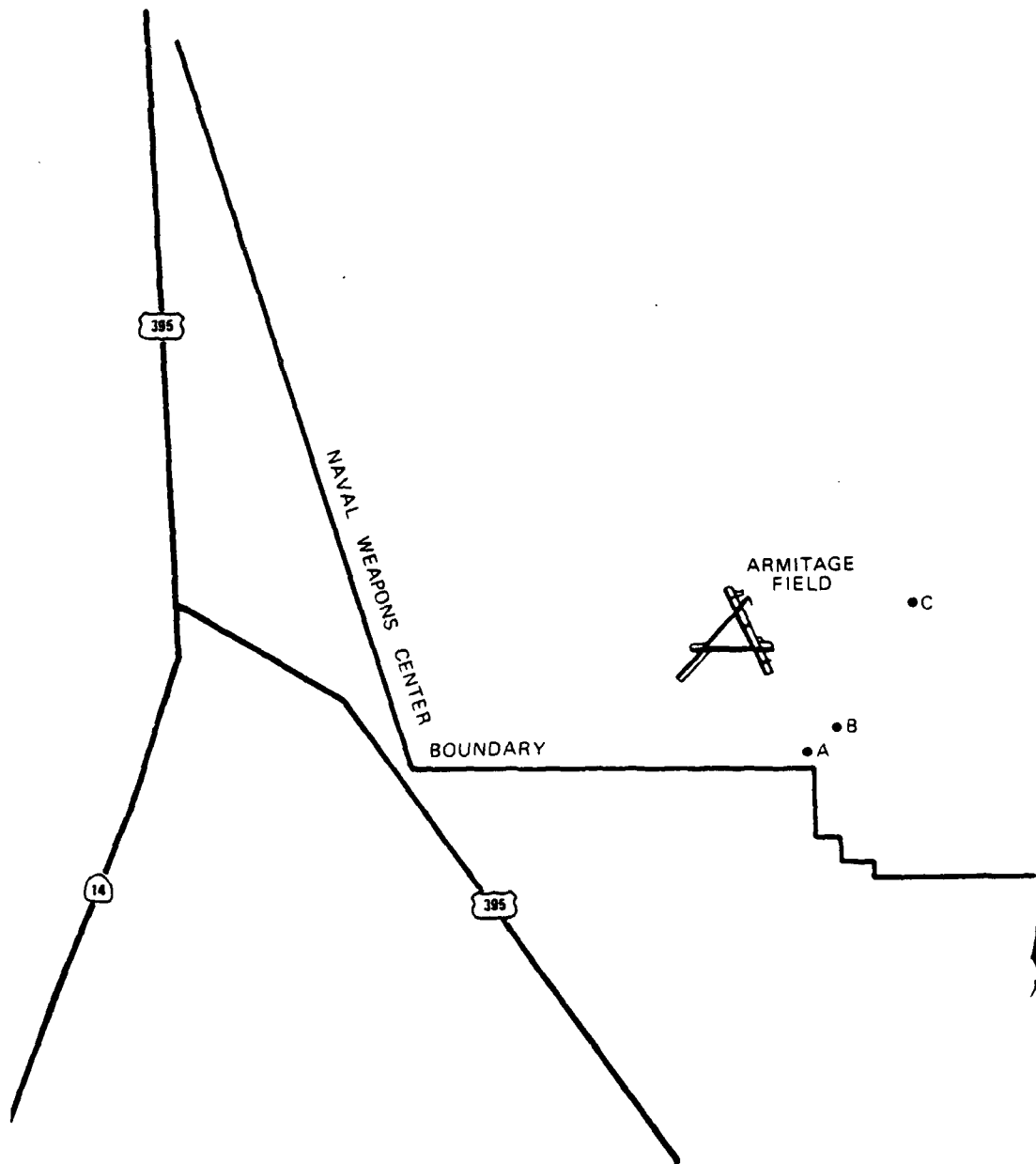
FIGURE 17. Approximate Locations of Three Thermal-Gradient Drill Sites at NWC.

SUMMARY AND RECOMMENDATIONS

The obvious conclusion one can draw from this study is that the geochemistry of groundwaters in Indian Wells Valley is complex. Using a computer classification of waters by principal cations and anions, of 254 water types possible under the classification scheme, some 55 occur in the Indian Wells Valley, Rose Valley, the Sierra, the Coso and Argus Ranges, the Coso Geothermal Field, Salt Wells, and Poison Canyon.

Groundwater Flow Cells

By lumping similar waters together, the following major groundwater flow cells can be delineated.

Sodium-Chloride Waters. These waters are found in the Coso Geothermal Field, China Lake Playa, southeastern Ridgecrest, Salt Wells, and Poison Canyon.

Sodium-Carbonate Waters. These waters are found in the Coso Geothermal Field (one site). In southwest Indian Wells Valley, two sites are noted. The presence of sodium-carbonate waters in these areas very possibly indicates geothermal inflow into the southwest part of the valley.

Sodium-Bicarbonate Waters. These waters occur in a horseshoe-shaped area from Inyokern up to the dividing line between T24S and T25S and back down to Michelson Laboratory at NWC. On the east side of the horseshoe area, an area of mixed waters—sodium-bicarbonate-chloride—occurs between the sodium-chloride brines of China Lake Playa and the sodium-bicarbonate waters, indicating mixing around the Playa.

Sulfate Waters of Various Types. The sulfate waters occur in Walker Well in the Sierra, the Tungsten Peak Mine, a well in 26S/38E-15, some wells about 2 miles north of Inyokern, and deep Rose Valley waters. The source of the sulfate may be oxidation of sulfides that are formed by mineralization or that occur in lake sediments (the Walker Well and Tungsten Peak Mine), or geothermal activity. The very shallow waters in "area R" at NWC are contaminated with sodium-sulfate-rich waters from the sewage ponds.

Alpine Waters. These waters are characteristic of the mountainous regions, and are calcium-sodium-magnesium-bicarbonate waters with low TDS.

Red Hill/Little Lake/Lumber Mill Site Waters. These waters are of somewhat variable classification by computer, but generally give similar modified Stiff diagrams. These are calcium-(sodium-magnesium)-bicarbonate-chloride-(sulfate) waters, and are probably a mixture of alpine, deep Rose Valley, and geothermal waters.

Groundwaters of the Inyokern Intermediate and Ridgecrest Well Fields. In these waters, sodium is usually the dominant cation, although sometimes calcium is. The magnesium content is usually low. Bicarbonate and chloride are the important anions. These waters could be formed by concentrating alpine waters by transpiration and evaporation and mixing with small amounts of geothermal waters.

Argus Range Waters. The waters of the Argus Range are sodium-calcium-magnesium-bicarbonate waters.

Variations in Water Quality

Water quality may degrade, improve, or remain constant with depth. In most cases water quality has changed too little with time to be identifiable. Exceptions are a few wells in the Ridgecrest area. Degradation may represent vertical leakage from low-temperature geothermal reservoirs in bedrock. Other possible areas of geothermal inflow are the southwest corner of the Valley and the Haystack Peak area of the Spangler Hills.

Geothermal Leakage Into Indian Wells Valley

It is highly probable that waters are entering Indian Wells Valley from the bedrock basement. There are good indications—measured temperatures, pseudo-temperature gradients, and chemical geothermometers—that there is geothermal leakage into the Valley west and just north and south of the main gate of NWC. Haystack Peak, which exhibits a very anomalous snowmelt pattern, may represent another source of geothermal leakage into the valley. These geothermal plumes may be a partial cause of some loss of water quality.

Water chemistry indicates probable geothermal leakage into the southwestern portion of the Valley, recognizing that the Little Dixie wash area of the El Paso Mountains is a deep circular sub-basin, separate from the Indian Wells Valley. The fact that a complex water occurs all the way from Red Hill in Rose Valley to the Brown Road turn in Indian Wells Valley indicates a major flow of groundwater from Rose Valley into Indian Wells Valley.

Further grounds for this belief are provided by the conditions at the lumber mill on California State Highway 395. When in operation, the lumber mill used about 1,000 acre-feet of water per year.* When collecting a sample there, millworkers told Baskin that there was very little drawdown. Lower Little Lake Spring flows about 1 cubic foot per second or over 700 acre-feet per year. Most of this flow infiltrates. These facts indicate that the estimate of 45 acre-feet a year entering Indian Wells Valley from Rose Valley by Bloyd and Robson (1971) is absurd. The 10,000 acre-feet estimate of Thompson (1929) seems more reasonable (and could be conservative).

Another source of recharge that has been neglected is leakage from the old aqueduct; Austin estimates this leakage to be about 4,000 acre-feet in the Indian Wells and Rose Valleys.** Another source of recharge not usually considered is water from the Sierran granites and metamorphic rocks. Volcanic rocks may have permeability because of faulting, jointing, vesicles, or rubble areas between flows. Faults, joints, and even micro-fractures all contribute to permeability. The Tungsten Peak Mine, when last in operation (and never completely dewatered), made 110 gpm of water or 180 acre-feet per year.*** Another source of this type of calcium-sodium-sulfate water is a shallow well in 26S/38E-22D.

We believe that enough usable chemical data are now available to enable interaction of flow data with structural data. After the geochemical data have been integrated with the structural and other data there may they be additional critical sites that should be sampled. It might also be desirable to obtain Tritium ages on some of the fundamental water types.

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* Dr. C. F. Austin, personal communication with Dr. J. A. Whelan, June 1988.
** Dr. C. F. Austin, personal communication with Dr. J. A. Whelan, June 1988.
*** Dr. C. F. Austin, personal communication with Dr. J. A. Whelan, June 1958.

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Appendix A

INDIAN WELLS VALLEY GEOTHERMOMETRY
1920 TO 1986

TABLE A-1. Indian Wells Valley Geothermometry 1920 to 1986.

All temperatures in °C.

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
28S/37E-13F01	6-5-53	–	–	–	114	31	–	–
28S/37E-31D01	6-5-53	–	–	–	57	24	–	–
27S/38E-31D01	4-20-62	51	57	18	99	55	–	–
27S/38E-28R01	3-22-46	74	78	42	130	23	–	–
	3-24-60	69	74	37	141	27	–	21.7
27S/40E-15L01	6-27-61	92	94	61	159	69	–	24.4
	6-29-72	95	97	65	161	68	–	32.0
	3-7-74	94	96	63	164	72	–	–
27S/40E-17G01	10-6-69	96	97	66	–	–	–	–
	1-29-70	–	–	–	94	66	–	–
27S/40E-09P01	10-10-51	–	–	–	–	–	–	–
	6-1-53	–	–	–	89	77	–	–
	6-29-72	105	106	76	114	54	–	30.0
27S/40E-07G01	8-10-60	113	112	84	125	69	–	30.0
27S/40E-09L02	9-11-64	–	–	–	–	–	–	–
27S/40E-10J01	8-5-53	–	–	–	114	70	–	25.6
27S/39E-07R01	3-22-46	92	94	61	147	33	–	–
	3-14-55	–	–	–	152	34	–	–
	3-24-60	81	84	49	163	38	–	21.0
27S/40E-10R01	3-7-74	39	47	7	172	158	137	–
	3-25-75	20	30	-13	182	173	136	17.5
	8-19-76	42	50	10	170	155	134	25.0
	6-28-78	39	47	7	174	159	135	26.0
	6-6-79	34	42	1	162	153	133	28.0
	5-28-80	27	36	-6	174	162	135	27.5
27S/40E-10E01	6-19-62	105	105	75	113	94	–	28.9
27S/40E-10B01	4-29-46	69	74	37	112	77	65	–

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
27S/40E - 10C01	9-25-46	110	109	80	109	74	—	—
	7-9-53	—	—	—	73	52	—	25.6
	4-6-55	—	—	—	125	80	—	25.8
27S/40E - 10D01	9-24-46	105	106	76	111	71	—	—
27S/40E - 10H01	8-11-60	99	100	69	105	66	—	25.0
	10-11-61	97	98	67	97	61	—	—
	7-20-62	96	97	66	109	72	—	—
	10-24-63	98	99	68	119	71	—	—
	9-8-64	91	93	60	73	42	—	—
	3-23-66	95	97	65	118	69	—	21.1
	3-8-67	—	—	—	111	67	—	—
27S/40E-11D03	6-1-53	—	—	—	116	73	—	—
27S/40E -09B01	4-30-46	96	97	66	126	54	—	—
27S/40E- 10A02	6-1-53	—	—	—	145	71	44	—
27S/40E- 11C02	4-24-46	102	103	72	107	62	—	—
	9-23-46	107	107	78	105	71	—	—
27S/40E 08B02	5-19-70	—	—	—	133	47	—	—
27S/40E- 10A01	6-1-53	—	—	—	119	82	—	—
	4-6-55	—	—	—	124	69	—	23.9
	9-18-58	—	—	—	141	69	—	—
	6-17-72	102	103	72	115	71	65	25.0
27S/40E- 08A01	10-25-49	100	102	70	—	—	—	—
	6-1-53	—	—	—	85	79	—	—
	7-2-70	—	—	—	279	41	—	—
27S/40E- 03B01	3-7-74	99	100	69	154	65	—	—
	3-25-75	98	99	68	138	71	60	18.0
	8-19-76	102	103	72	115	72	57	24.5
	6-29-78	92	94	61	130	73	—	30.0

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	6-6-79	99	100	69	120	71	60	24.0
	5-27-80	101	102	71	127	82	—	23.5
	6-15-82	107	107	78	111	69	—	25.5
27S/40E-03P01	9-25-46	32	41	-1	114	78	66	—
	6-1-53	—	—	—	106	70	—	—
	6-5-53	—	—	—	98	62	—	—
27S/40E-02N01	4-27-46	45	53	13	132	136	32	—
27S/40E-02J01	2-26-68	105	106	76	113	62	—	—
	4-3-69	105	106	76	123	65	—	—
	6-17-72	107	107	78	110	66	—	25.0
	3-6-74	109	109	80	122	69	—	—
	3-25-75	103	103	73	121	69	—	22.5
	8-19-76	108	108	79	119	67	—	21.5
	6-28-78	105	106	76	116	70	—	25.0
	6-1-79	105	106	76	118	71	—	23.0
	5-23-80	108	108	79	117	70	—	19.5
27S/40E-01N01	5-1-46	93	95	62	114	69	—	—
	9-23-46	89	92	59	118	68	—	—
	6-4-53	—	—	—	112	71	61	24.4
27S/40E-01K01	9-3-29	111	110	81	—	—	—	—
27S/40E-04L01	6-1-53	—	—	—	98	71	69	26.7
	4-7-55	—	—	—	116	77	—	27.8
	3-31-70	—	—	—	111	81	33	—
	10-1-71	—	—	—	113	83	42	—
	6-00-75	—	—	—	119	74	55	—
27S/40E-01K02	6-1-53	—	—	—	136	93	47	—
	6-17-72	106	106	77	128	83	—	25.0

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
27S/40E-01G02	9-23-46	112	111	83	135	93	—	—
27S/40E-02H01	6-18-72	104	104	74	109	73	—	25.0
	5-1-75	79	83	48	108	79	—	—
27S/40E-06H01	2-14-72	—	—	—	88	60	—	—
27S/40E-02G01	6-15-72	106	106	77	145	68	—	23.0
27S/40E-02F01	6-16-72	111	110	81	189	73	—	24.0
27S/40E-01G01	9-17-85	78	82	47	145	35	—	24.5
27S/40E-02A01	6-14-72	110	109	80	134	86	74	24.0
27S/40E-04C02	3-31-70	—	—	—	149	72	63	—
	6-00-75	—	—	—	137	80	55	—
	3-23-77	—	—	—	143	68	—	—
27S/40E-04B02	6-1-53	—	—	—	156	57	—	25.6
	5-12-66	—	—	—	114	56	—	—
	7-14-67	101	102	71	—	—	—	—
27S/40E-04C01	5-22-64	—	—	—	179	63	—	26.7
	3-31-70	—	—	—	163	59	—	—
	6-00-75	—	—	—	161	65	—	—
26/40E-35Q02	6-16-72	119	117	90	199	95	71	24.0
26S/40E-33P04	3-31-70	—	—	—	152	72	52	—
	6-00-75	—	—	—	132	94	37	—
	3-23-77	—	—	—	133	130	—	—
26S/40E-33P01	2-7-45	96	97	66	191	53	—	—
	6-1-53	94	96	63	183	48	—	24.4
26S/40E-33P02	2-7-45	100	101	70	181	51	—	—
	3-31-70	—	—	—	204	60	—	—
26S/40E-35Q01	9-24-46	92	94	61	—	—	—	—
26S/40E-34B01	5-1-46	99	100	69	204	60	—	—
	9-24-46	101	102	71	204	63	—	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
26S/40E- 33P03	4-30-46	98	99	68	181	49	—	—
	9-25-46	96	97	66	178	50	—	—
	7-14-67	96	97	66	—	—	—	—
26S/40E - 34N01	4-30-46	99	100	69	212	65	—	—
	9-24-46	102	103	72	212	65	—	—
	6-2-53	—	—	—	177	67	—	25.6
	4-6-55	—	—	—	183	65	—	25.6
	10-17-56	—	—	—	163	64	—	26.1
	9-18-57	—	—	—	177	65	—	25.6
	9-18-58	—	—	—	156	59	—	—
	10-20-59	—	—	—	165	57	—	26.1
	8-11-60	100	101	70	185	60	—	25.6
	8-1-61	79	83	48	185	63	—	—
	7-18-62	91	93	60	147	59	—	—
	10-14-63	93	95	62	129	36	—	—
	9-15-64	94	96	63	192	55	—	—
	9-21-65	78	82	47	206	61	—	—
	5-16-66	95	97	65	205	66	—	—
	9-7-66	93	95	62	182	62	—	—
	10-23-67	88	91	57	182	63	--	—
	6-21-68	87	90	56	185	60	—	—
	11-4-68	92	94	61	185	58	—	—
	10-20-69	96	97	66	185	58	—	--
	6-1-70	96	97	66	198	62	—	—
	10-20-70	93	95	62	194	56	—	—
	6-23-71	85	88	54	212	60	—	—
	10-27-71	91	93	60	208	60	—	—
	6-6-72	69	74	37	209	58	—	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	10-25-73	78	82	47	177	58	—	—
	6-00-74	72	77	40	197	59	—	—
	5-12-76	99	100	69	172	57	—	—
	7-31-78	94	96	63	211	60	—	—
	3-29-80	97	98	67	206	64	—	—
26S/40E-32K01	11-12-77	—	—	—	138	98	95	—
	12-1-77	—	—	—	83	95	—	—
26S/40E-32E01	7-9-53	—	—	—	197	44	—	26.7
26S/40E-32E02	6-17-72	77	81	45	192	44	—	27.0
26S/40E-36A01	3-8-54	—	—	—	164	150	64	22.2
	3-6-74	99	100	69	132	79	—	—
	3-25-75	91	93	60	141	82	—	20.0
	8-19-76	93	95	62	130	77	—	22.5
	6-29-78	86	89	55	131	65	—	25.5
	6-6-79	88	91	57	137	79	—	23.0
	5-27-80	78	82	47	128	76	—	22.5
	6-14-82	79	83	48	141	77	—	22.0
	6-17-85	102	103	72	138	66	—	22.0
26S/40E-32D01	4-30-46	24	33	-9	219	60	—	—
	9-24-46	5	15	-28	234	66	—	—
	7-10-53	—	—	—	191	49	—	27.2
26S/40E-33A02	6-1-53	—	—	—	192	165	101	—
26S/38E-35B01	6-15-82	53	60	21	89	53	—	29.0
26S/40E-28J01	6-17-72	106	106	77	285	202	103	27.0
	6-29-78	105	105	75	295	206	96	27.5
	6-1-79	107	107	78	309	210	87	24.0
	5-27-80	95	97	65	235	88	81	21.0

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	6-11-82	110	109	80	298	206	86	25.0
	8-10-84	108	108	79	331	97	78	24.0
26S/40E-30K03	10-24-74	—	—	—	110	59	—	—
	6-4-75	—	—	—	72	105	—	—
	3-23-77	—	—	—	64	99	—	—
26S/39E-30J01	10-22-52	—	—	—	163	45	—	—
	6-5-53	—	—	—	153	44	—	—
	4-17-61	91	93	60	150	40	—	—
26S/40E-30K01	3-31-70	—	—	—	131	58	—	—
	6-00-75	—	—	—	137	82	—	—
	3-23-77	—	—	—	132	61	—	—
26S/40E-28H01	6-1-53	—	—	—	286	94	76	24.4
26S/38E-27G01	9-17-85	61	67	29	155	50	—	29.5
26S/40E-29F01	11-2-70	—	—	—	226	59	—	—
26S/40E-30K02	3-31-70	—	—	—	56	68	—	—
	6-00-75	—	—	—	110	118	—	—
	2-28-77	—	—	—	81	59	—	—
26S/40E-30G01	4-30-46	39	47	7	322	215	84	—
26S/39E-25G01	2-17-67	—	—	—	234	51	—	—
	9-22-67	39	47	7	126	41	—	—
26S/40E-30G02	8-5-53	—	—	—	231	60	—	26.7
26S/40E-26F01	5-26-72	118	117	90	176	94	60	23.0
	6-4-82	117	115	88	180	93	55	24.5
26S/39E-30F01	8-1-61	75	79	43	157	41	—	—
	6-7-62	72	77	40	154	44	—	—
	9-15-64	88	91	57	138	36	—	—
	6-21-65	78	82	47	150	45	—	—
	5-16-66	85	88	54	158	48	—	—

TABLE A-1. (Contd.)

Location	Date	Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	Measured temperature
	9-7-66	79	83	48	259	81	—	-
	6-00-74	63	69	31	128	34	—	-
	5-1-75	67	72	35	130	41	—	-
	5-12-76	86	89	55	124	42	—	-
26S/39E-30F03	5-25-67	82	85	51	145	43	—	-
	10-16-67	79	83	48	139	41	—	—
	11-4-68	78	82	47	142	40	—	—
	10-20-69	86	89	55	136	40	—	—
	6-1-70	81	84	49	139	39	—	—
	10-20-70	81	89	49	135	38	—	—
	6-23-71	86	89	55	149	42	—	—
	10-27-71	77	81	45	145	40	—	—
	6-6-72	—	—	—	148	41	—	—
	10-25-73	69	74	37	133	38	—	—
26S/39E-26D01	1-26-20	94	96	63	—	—	—	—
26S/39E-30C01	5-1-75	79	83	48	190	64	—	—
26S/40E-26B01	7-8-53	—	—	—	152	60	—	23.3
26S/40E-30C02	4-30-46	39	47	7	323	216	85	—
26S/39E-28C02	0-0-57	—	—	—	204	62	—	—
26S/40E-29D01	6-17-72	100	101	70	327	83	78	26.0
26S/39E-28B02	10-7-70	—	—	—	162	35	—	—
26S/40E-28A03	6-1-53	—	—	—	208	173	80	—
26S/40E-28A01	6-1-53	—	—	—	208	173	80	—
26S/40E-28C01	6-1-53	—	—	-	224	74	—	—
26S/39E-25C01	10-22-52	—	-	—	194	39	—	21.1
26S/40E-24B01	3-9-54	—	-	—	197	179	—	21.7

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
26S/40E- 22P02	6-1-72	124	121	96	239	98	43	24.0
	10-3-83	125	122	97	248	95	37	—
	8-8-84	124	121	96	246	96	36	24.0
	6-10-85	126	124	99	244	95	37	26.0
26S/40E 22P01	2-0-54	97	98	67	102	125	110	32.2
	6-17-72	79	83	48	89	116	108	27.0
	6-22-78	14	24	-19	90	116	111	29.5
	5-17-79	19	29	-14	96	121	119	29.0
	5-28-80	78	82	47	109	133	79	27.0
26S/39E- 20Q01	4-26-46	82	85	51	—	—	—	—
26S/40E- 20N01	4-30-46	92	94	61	246	64	—	—
	6-1-53	—	—	—	250	56	—	25.6
26S/40E- 19P01	11-20-59	—	—	—	256	56	—	30.6
	3-24-80	74	78	42	58	53	—	—
26S/39E- 19P01	10-22-52	—	—	—	157	42	—	28.3
	6-1-53	89	92	59	153	39	—	27.8
	8-1-61	75	79	43	157	39	—	—
	6-7-62	79	83	48	163	43	—	—
	4-00-63	85	88	54	79	7	—	—
	5-00-64	86	89	55	190	55	—	—
	9-15-64	83	86	52	139	33	—	—
	6-21-65	78	82	47	156	40	—	—
	5-16-66	51	57	18	163	45	—	—
	9-7-66	82	85	51	149	35	—	—
	10-23-67	81	84	49	136	37	—	—
	6-5-68	89	92	59	132	36	—	—
	10-4-68	75	79	43	136	36	—	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	10-26-69	88	91	57	136	35	—	—
	6-1-70	75	79	43	139	39	—	—
	10-26-70	82	85	51	139	39	—	—
	6-23-71	87	90	56	164	45	—	—
	10-27-71	74	78	42	138	36	—	—
	6-00-72	65	71	33	149	35	—	—
	10-25-73	78	82	47	136	40	—	—
	6-00-74	70	75	39	127	31	—	—
	5-12-76	85	88	54	129	34	—	—
	7-31-78	77	81	45	143	37	—	—
	5-4-79	87	90	56	157	44	—	—
	3-29-80	78	82	47	149	38	—	—
	9-18-85	86	89	55	149	38	—	27.0
26S/39E-24R01	4-5-55	—	—	·	179	85	68	27.2
	10-14-55	—	—	—	180	69	31	26.7
	10-17-56	—	—	—	223	84	—	28.3
	9-18-57	—	—	—	258	56	—	26.7
	9-13-58	—	—	—	251	70	—	—
26S/39E-24Q01	6-6-52	91	93	60	222	48	—	26.1
	10-14-55	—	—	—	204	42	—	26.1
	10-17-56	—	—	—	236	52	—	26.7
	9-14-57	—	—	—	229	48	—	26.7
	9-18-58	—	—	—	179	35	—	—
	10-14-63	77	81	45	162	38	—	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
26S/39E-24P01	3-6-58	88	91	57	156	59	—	30.6
	9-18-58	—	—	—	87	57	—	—
	11-20-59	—	—	—	75	58	—	33.9
	8-11-60	—	—	—	152	51	—	30.0
	8-1-61	75	79	43	171	55	—	—
	6-7-62	79	83	48	107	63	—	—
	10-14-63	77	81	45	162	38	—	—
	5-00-64	81	84	49	151	41	—	—
	9-15-64	79	83	48	144	48	—	—
	6-21-65	72	77	40	156	56	—	—
	5-16-66	79	83	48	175	67	—	—
	9-7-66	74	78	42	143	57	—	—
	10-23-67	79	83	48	197	45	—	—
	6-5-68	67	72	35	128	51	—	—
	11-4-68	70	75	39	152	46	—	—
	6-1-70	81	84	49	179	43	—	—
	6-23-71	74	78	42	138	46	—	—
	10-27-71	74	78	42	147	50	—	—
	6-6-72	53	60	21	128	51	—	—
	10-25-73	77	81	45	137	44	—	—
	6-00-74	78	82	47	112	41	—	—
	5-4-79	75	79	43	139	50	—	—
26S/40E-22P03	90-31-83	74	78	42	89	120	76	26.0
	8-8-84	86	89	55	92	126	104	27.0
	1-9-86	1	12	-32	139	154	147	24.5
26S/40E-22P04	10-31-83	110	109	80	291	204	—	—
	8-4-84	110	109	80	248	77	74	26.0
	1-9-86	107	107	78	269	82	67	24.5

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
26S/40E-22N01	7-4-53	—	—	—	141	146	42	—
	4-4-55	—	—	—	133	137	37	23.9
	11-15-68	97	98	67	190	86	36	—
	6-28-72	105	106	76	210	81	39	25.0
	3-6-74	100	101	70	225	87	39	—
	3-26-75	99	100	69	239	88	35	20.5
	8-19-76	107	107	78	217	80	40	25.0
	6-20-78	102	103	72	230	80	38	23.0
	5-31-79	104	104	74	241	82	39	25.5
	5-23-80	82	85	51	112	122	23	22.0
26S/40E-19N01	4-30-46	105	106	76	262	54	—	—
	11-20-59	—	—	—	256	56	—	30.6
26S/40E-21K01	4-30-46	32	41	-1	433	295	180	—
26S/39E-24K01	5-4-79	89	92	59	127	49	—	—
26S/39E-24N01	10-27-60	75	79	43	137	36	—	—
	4-00-63	59	66	27	96	37	—	—
	10-14-63	74	78	42	300	100	85	—
	5-00-64	83	86	52	152	51	—	—
	9-15-64	85	88	54	206	43	—	—
	5-16-66	82	85	51	172	61	—	—
	9-7-66	79	83	48	174	45	—	—
	10-23-67	78	82	47	175	42	—	—
	6-5-68	69	74	37	145	43	—	—
	11-4-68	77	81	45	148	44	—	—
	10-20-69	77	81	45	147	44	—	—
	6-1-70	78	82	47	165	45	—	—
	10-20-70	81	84	49	196	38	—	—
	6-23-71	83	86	52	177	48	—	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	10-27-71	75	79	43	176	48	—	—
	6-6-72	63	69	31	161	41	—	—
	10-25-73	59	66	27	173	42	—	—
	5-1-75	63	69	31	146	48	—	—
	5-12-76	99	100	69	142	48	—	—
	7-31-78	69	74	37	207	41	—	—
	5-4-79	81	84	49	179	43	—	—
	3-29-80	72	77	40	204	55	—	—
	9-18-85	83	86	52	201	43	—	25.5
26S/40E-22K01	6-1-72	116	115	87	208	91	49	25.5
	10-31-83	107	107	78	213	170	—	—
	8-8-84	101	102	71	217	172	21	24.0
	6-12-85	109	109	80	210	94	36	25.0
26S/39E-19K01	10-12-60	85	88	54	149	34	—	—
	10-14-63	70	75	39	104	25	—	—
	5-00-64	85	88	54	116	26	—	—
	9-15-64	81	84	49	150	35	—	—
	1-10-65	72	77	40	134	40	—	—
	1-11-65	77	81	45	173	53	—	—
	1-12-65	79	83	48	183	54	—	—
	8-12-65	74	78	42	167	37	—	—
	5-16-66	85	88	54	165	39	—	—
	9-7-66	78	82	47	141	36	—	—
	6-21-67	83	86	52	143	36	—	—
	10-23-67	82	85	51	154	34	—	—
	6-5-68	74	78	42	152	33	—	—
	11-4-68	83	86	52	149	36	—	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	10-20-69	85	88	54	155	33	—	—
	6-1-70	81	84	49	162	35	—	—
	10-20-70	77	81	45	164	39	—	—
	6-23-71	85	88	54	170	38	—	—
	10-27-71	78	82	47	164	35	—	—
	6-00-72	70	75	39	163	35	—	—
	6-00-74	70	75	39	133	36	—	—
	5-1-75	65	71	33	136	36	—	—
	5-12-76	48	55	15	145	41	—	—
	7-31-78	63	69	31	175	35	—	—
	5-4-79	82	85	51	147	32	—	—
	3-29-80	82	85	51	155	34	—	—
26S/39E - 23E01	4-27-46	79	83	48	208	49	—	—
26S/40E - 23J01	5-4-72	117	116	89	135	139	45	22.0
	8-9-84	108	108	79	331	97	78	—
26S/40E - 24M01	6-12-72	107	107	78	193	172	57	22.0
26S/40E - 23L01	6-2-72	105	105	75	109	126	42	25.0
26S/40E - 22J01	6-2-72	117	115	88	219	176	17	25.0
	10-31-83	115	114	86	209	172	—	—
	8-8-84	117	116	89	213	176	—	25.0
	6-11-85	127	124	99	217	176	—	28.0
26S/39E - 24E01	4-27-46	81	84	49	185	41	—	—
26S/39E - 23J01	10-17-60	85	88	54	206	45	—	—
	4-00-63	82	85	51	126	15	—	—
	10-14-63	82	85	51	164	22	—	—
	5-00-64	85	88	54	190	44	—	—
	9-15-69	86	89	55	199	34	—	—

TABLE A-1. (Contd.)

Location	Date	Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	Measured temperature
	9-21-65	74	78	42	217	46	—	—
	5-16-66	82	85	51	217	47	—	—
	9-7-66	79	83	48	163	36	—	—
	10-23-67	81	84	49	197	38	—	—
	6-5-68	75	79	43	170	38	—	—
	11-4-68	77	81	45	171	39	—	—
	10-20-69	87	90	56	176	39	—	—
	6-1-70	82	85	51	164	41	—	—
	10-20-70	79	83	48	200	40	—	—
	10-27-71	79	83	48	207	44	—	—
	6-6-72	65	71	33	206	43	—	—
	10-25-73	79	83	48	183	47	—	—
	6-00-74	69	74	37	181	43	—	—
	5-1-75	70	75	39	161	35	—	—
	5-12-76	48	55	15	167	38	—	—
	7-31-78	75	79	43	224	30	—	—
	5-4-79	85	88	54	183	34	—	—
	4-13-86	83	86	52	191	37	—	24.0
26S/40E-21G01	6-8-72	105	106	76	289	202	91	24.0
	8-7-84	100	101	70	278	200	97	25.0
	6-10-85	—	—	—	303	211	98	24.5
26S/40E-23G01	5-24-72	111	110	81	98	128	33	22.0
	8-7-84	110	109	80	103	125	—	22.0
	6-11-85	92	94	61	104	127	—	23.0
26S/40E-22H01	6-12-72	118	117	90	216	181	—	24.0
	6-19-78	122	120	94	224	186	—	26.0
	5-15-79	120	118	92	237	191	—	23.0
	5-20-80	—	—	—	238	189	—	23.0

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	6-8-82	124	122	96	226	180	22	25.0
	8-8-84	124	121	96	224	178	23	23.5
	6-12-85	130	126	102	229	180	23	24.5
26S/40E-22H02	6-12-72	101	102	71	118	132	—	25.0
	6-19-78	88	91	57	127	145	—	25.0
	5-15-79	91	93	60	120	141	—	23.5
	5-20-80	95	97	65	126	136	—	23.5
	6-8-82	92	94	61	116	127	—	25.0
	10-31-83	94	96	63	119	130	—	—
	6-12-85	92	94	61	118	128	—	25.5
26S/40E-22H03	6-13-72	105	105	75	162	147	22	24.0
	6-19-78	101	102	71	156	148	—	25.0
	5-15-79	107	107	78	158	151	—	24.0
	5-20-80	111	110	81	150	150	—	24.0
	6-8-82	110	109	80	145	138	—	25.2
	8-7-84	117	116	89	213	176	—	—
	8-4-84	113	112	84	149	140	—	24.0
	6-12-85	120	118	91	157	146	—	26.5
	4-17-86	119	117	90	147	139	—	22.0
26S/39E-20F01	9-15-69	83	86	52	186	38	—	—
	5-22-69	—	—	—	213	49	—	—
26S/40E-23A01	5-26-72	113	112	84	141	146	53	22.0
	6-14-78	105	106	76	142	145	53	24.0
	5-17-79	106	106	77	140	143	66	25.0
	5-21-80	110	109	80	139	143	59	24.5
	6-10-82	111	111	82	133	138	51	24.5

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
26S/40E-23A02	5-26-72	121	119	93	145	149	61	22.5
	6-19-78	110	109	80	143	148	55	23.5
	5-17-79	111	111	82	152	150	63	25.5
	6-10-82	118	117	90	138	143	58	24.0
26S/40E-23D01	10-31-83	77	81	45	92	125	83	—
	1-7-86	35	44	3	95	127	94	23.0
26S/40E-23D02	10-31-83	28	37	-5	113	136	—	—
	1-9-86	86	89	55	134	145	—	22.0
26S/40E-21A01	6-13-72	88	91	57	159	145	83	25.0
	8-8-84	111	110	81	150	146	58	29.0
	6-10-85	110	109	80	160	152	58	25.5
	4-17-86	114	113	85	160	151	50	22.0
26S/40E-23C01	7-9-53	—	—	—	137	64	—	21.1
26S/40E-24C01	7-9-53	—	—	—	182	67	—	22.2
	5-26-72	81	84	49	86	103	47	21.0
	6-23-78	48	55	15	95	95	58	21.5
	5-21-80	35	44	3	76	100	52	20.0
	6-10-82	63	69	31	63	85	—	19.5
26S/40E-22B01	6-18-72	109	108	79	139	142	—	25.0
	8-4-84	115	114	86	135	143	—	23.0
	6-12-85	122	120	94	136	144	—	26.0
	4-17-86	120	118	92	136	152	—	22.5
26S/40E-18N01	4-24-46	24	33	-9	169	174	—	—
	4-5-55	—	—	—	181	73	54	26.1

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
26S/40E-17N01	10-13-55	—	—	—	274	201	145	23.9
26S/40E-15N01	4-28-46	87	90	56	99	126	—	—
	6-21-78	59	66	27	96	121	40	26.0
	5-31-79	3	14	-30	103	126	67	25.0
	5-22-80	75	79	43	95	123	50	24.5
26S/40E-17R01	6-18-72	104	104	74	228	60	—	23.0
	8-7-84	104	104	74	221	54	—	22.4
	6-10-85	106	106	77	219	56	—	24.0
26S/38E-15Q01	8-5-53	—	—	—	152	32	—	20.6
26S/40E-13N01	6-14-72	59	66	27	116	58	—	19.0
	6-23-78	39	47	7	107	60	—	23.0
	5-21-80	1	12	-32	87	60	—	31.0
26S/40E-15N02	6-14-82	74	78	42	125	87	—	25.0
	8-8-84	108	108	79	99	132	58	23.0
	6-11-85	109	109	80	104	136	55	25.0
26S/39E-18K01	5-13-70	—	—	—	180	41	—	—
26S/40E-14L01	6-12-72	117	116	89	154	141	51	21.5
	6-20-78	107	107	78	133	130	53	24.0
	5-15-79	107	107	78	116	75	65	24.0
	5-20-80	102	103	72	156	142	33	21.5
	8-9-84	116	115	87	149	90	60	21.0
	6-11-85	121	119	93	152	93	61	22.5
26S/40E-14H01	6-21-72	42	50	10	89	52	—	22.0
26S/40E-17J01	6-18-72	91	93	60	214	60	—	23.0
	9-7-84	94	96	63	213	53	—	22.5
	6-10-85	99	100	69	207	52	—	24.0
26S/40E-18E01	4-29-46	101	102	71	118	133	54	—
26S/39E-14E01	4-27-46	86	89	55	269	60	—	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
26S/40E-15E02	4-28-46	59	66	27	—	—	—	—
	4-4-55	—	—	—	79	118	63	22.2
	3-5-74	93	95	62	71	124	120	—
	3-26-75	89	92	59	76	124	122	20.5
	9-18-76	34	43	1	66	124	97	24.0
	6-20-78	102	103	72	71	119	—	23.5
	5-22-80	95	97	65	76	124	—	23.0
26S/40E-15E01	4-28-46	114	113	85	84	82	—	—
	7-6-53	—	—	—	89	79	67	21.1
	4-4-55	—	—	—	103	96	44	21.1
	6-29-72	111	110	81	96	81	—	23.0
	3-5-74	99	100	69	111	96	—	—
	3-26-75	92	94	61	140	136	85	20.5
	8-18-76	98	99	68	106	86	82	22.0
	6-20-78	92	94	61	103	89	85	22.5
	5-31-79	92	94	61	102	94	90	26.0
	5-22-80	100	101	70	101	91	86	25.5
	6-10-82	55	62	23	94	83	—	24.5
26S/38E-17E01	1-12-55	—	—	—	174	37	—	—
26S/40E-13C01	6-14-72	65	71	33	144	90	—	22.0
	6-29-78	57	64	25	132	90	—	35.0
	6-6-79	42	50	10	138	96	—	19.0
	5-21-80	48	55	15	128	88	—	32.0
	6-11-82	51	57	18	125	82	—	19.0
26S/40E-14B01	6-12-72	116	115	87	121	84	81	20.0
	6-20-78	110	109	80	123	92	79	22.0
	5-15-79	109	109	80	59	48	—	22.0
	5-20-80	122	120	94	123	92	80	20.0

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	6-9-82	120	118	92	120	87	62	20.5
	8-6-84	117	116	89	121	87	79	19.0
	6-11-85	104	104	74	121	90	78	20.0
	4-16-86	120	118	91	119	92	67	18.5
26S/40E-7N01	1-28-20	86	89	55	–	–	–	–
	4-29-46	88	91	57	177	39	–	–
26S/39E-11Q01	4-27-46	108	108	79	244	54	–	–
26S/40E-8Q01	4-28-46	59	66	27	163	69	–	–
26S/40E-11N02	8-9-84	117	116	89	141	135	58	21.0
26S/40E-8N01	4-28-76	103	103	73	86	160	–	–
26S/39E-10N01	1-24-46	83	86	52	174	37	–	–
26S/40E-10N01	4-28-46	99	100	69	74	72	67	–
	7-6-53	–	–	–	96	112	33	21.1
26S/39E-7N01	4-26-46	85	88	54	155	41	–	22.0
	8-26-49	63	69	31	–	–	–	–
	3-27-51	77	81	45	–	–	–	–
	10-22-52	–	–	–	157	42	–	22.8
	1-18-71	–	–	–	163	51	–	–
26S/40E-12R01	6-29-78	-15	-3	-48	139	137	61	23.0
	6-6-79	-17	-5	-49	–	–	–	21.5
	5-27-80	-2	9	-35	139	136	52	20.5
26S/39E-12N01	4-27-46	93	95	62	189	38	–	–
26S/40E-12Q01	6-29-78	-21	-8	-53	137	136	69	21.0
	5-15-79	-51	-37	-82	142	144	96	24.0
	5-27-80	-11	-1	-43	144	144	52	25.5
	6-12-85	-21	-8	-53	137	143	87	–

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
26S/40E-11J01	7-4-53	−	−	−	145	98	84	21.7
	6-13-72	124	121	96	107	126	61	21.0
	3-7-74	19	29	−14	116	147	107	−
	3-25-75	−14	−2	−46	135	169	165	17.0
	8-18-76	67	72	35	133	153	71	26.5
	6-22-78	100	101	70	108	133	60	24.0
	5-28-80	48	55	15	126	145	57	20.5
26S/40E-11J03	8-9-84	137	133	110	95	121	51	27.0
	6-11-85	104	104	74	89	116	56	−
26S/39E-8K01	4-27-46	83	86	52	131	40	−	−
26S/39E-12E01	1-22-46	−	−	−	281	224	88	−
	4-28-46	32	41	−1	281	224	88	−
26S/39E-11E01	4-30-46	92	94	61	157	38	−	−
	7-27-53	−	−	−	168	37	−	22.0
	9-15-64	86	89	55	150	36	−	−
	6-21-65	70	75	39	164	42	−	−
	5-26-66	77	81	45	162	41	−	−
	9-7-66	82	85	51	138	31	−	−
	10-23-67	82	85	51	149	38	−	−
	6-5-68	77	81	45	140	39	−	−
	11-4-68	78	82	47	151	34	−	−
	10-20-69	87	90	56	148	34	−	−
	6-1-70	78	82	47	148	37	−	−
	6-23-71	92	94	61	164	40	−	−
	10-27-71	78	82	47	158	38	−	−
	6-00-72	63	69	31	156	34	−	−
	10-25-73	83	86	52	128	30	−	−
	6-00-74	69	74	37	124	74	−	−

TABLE A-1. (Contd.)

| Location | Date | Type of geothermometer | | | | | | Measured temperature |
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	5-1-75	67	72	35	133	45	—	—
	5-12-76	87	90	56	124	38	—	—
	7-31-78	77	81	45	154	43	—	—
	5-4-79	82	85	51	119	34	—	—
	3-27-80	82	85	51	146	41	—	—
26S/40E-10E01	1-24-20	81	84	49	—	—	—	—
	4-23-46	72	77	40	117	131	79	—
26S/39E-12G01	4-27-46	82	85	51	186	84	35	—
	6-29-78	-39	-26	-70	—	—	—	26.5
	5-15-79	15	25	-18	118	93	—	28.0
	5-27-80	38	46	6	119	96	—	23.5
	6-11-82	34	42	1	116	92	—	20.5
26S/40E-10F01	7-4-53	—	—	—	156	142	46	21.1
	6-13-72	110	109	80	128	79	—	21.0
	3-6-74	35	43	2	130	81	—	—
	3-25-75	57	64	25	141	74	—	17.0
	8-17-76	70	75	39	126	67	—	22.0
	6-22-78	39	47	7	137	75	—	23.0
	6-5-79	101	102	71	132	75	—	22.0
	5-20-80	94	96	63	146	86	—	22.5
	6-9-82	67	72	35	123	72	—	22.0
26S/40E-12A01	6-27-78	34	42	1	130	133	113	28.5
	5-17-79	39	47	7	98	94	—	20.5
	5-21-80	42	50	10	132	135	112	24.5
26S/40E-11A01	7-6-53	—	—	—	110	206	203	28.3
26S/41E-7E01	7-9-53	—	—	—	136	85	—	21.7
	6-27-78	59	66	27	76	117	99	22.0
	5-17-79	59	66	27	71	113	97	22.0

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	5-20-80	67	72	35	64	101	84	21.5
	6-20-82	69	74	37	80	124	67	22.0
26S/38E-2Q01	4-26-46	65	71	33	153	67	—	—
26S/41E-7G01	7-4-53	—	—	—	65	98	—	21.1
	1-29-78	53	60	21	58	114	—	21.0
	5-17-79	42	50	10	64	112	—	22.0
26S/40E-05P01	8-4-53	—	—	—	162	74	—	21.1
	5-15-58	—	—	—	147	65	—	21.7
	9-15-64	94	96	63	128	60	—	—
	6-16-66	95	97	65	136	71	—	—
	9-8-66	96	97	66	111	67	—	—
	6-5-68	88	91	57	121	61	—	—
	11-4-68	87	90	56	118	62	—	—
	10-20-69	98	99	68	150	80	45	—
	6-1-70	96	97	66	133	65	—	—
	10-20-70	82	85	51	124	61	—	—
	6-23-71	104	104	74	123	59	—	—
	10-27-71	89	92	59	114	63	—	—
	6-6-72	78	82	47	109	63	—	—
	10-25-73	93	95	62	95	36	—	—
	6-00-74	93	86	52	122	53	—	—
	5-1-75	79	83	48	120	63	—	—
	5-12-76	102	103	72	107	59	—	—
	7-31-78	88	91	57	118	58	—	—
	3-29-80	93	95	62	118	67	—	—
26S/40E-5P03	4-28-46	53	60	21	192	192	104	—
26S/39E-2N01	4-27-46	45	53	13	132	136	32	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
26S/40C- 1Q02	6-22-78	6	17	-27	90	129	—	31.0
	5-15-79	3	14	-30	94	139	128	27.0
	5-20-80	17	27	-16	95	138	113	32.0
	6-11-82	8	18	-25	83	127	126	20.5
26S/41E- 7001	6-29-78	26	35	-7	84	117	—	20.5
	5-17-79	45	53	13	74	115	—	25.5
	5-21-80	17	27	-16	94	140	—	21.5
26S/40E- 1Q01	6-22-78	9	19	-24	100	120	—	37.0
	5-16-79	-5	6	-38	130	158	155	20.0
	5-20-80	82	85	51	130	170	111	22.0
26S/40E- 1J01	7-8-53	—	—	—	106	153	51	21.1
	6-13-72	42	50	10	113	165	59	21.0
	6-22-78	39	47	7	109	164	54	23.0
	5-16-79	65	71	33	104	159	44	21.5
	5-21-80	45	53	13	126	178	63	19.5
	6-10-82	48	55	15	102	155	52	21.0
26S/40E- 6E01	4-26-46	96	97	66	148	42	—	—
26S/38E- 1G01	10-6-52	—	—	—	159	56	—	22.8
26S/38E- 1G02	1-26-73	—	—	—	157	60	—	—
26S/40E- 5F01	4-26-46	97	98	67	179	77	—	—
	8-3-53	—	—	—	130	56	—	21.0
	9-15-64	86	89	55	102	29	—	—
	6-21-65	74	78	42	152	50	—	—
	5-16-66	88	91	57	144	52	—	—
	9-7-66	86	89	55	110	48	—	—
	10-23-67	86	89	55	135	46	—	—
	6-5-68	79	83	48	130	42	—	—
	11-4-68	99	100	69	133	45	—	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	10-30-69	92	94	61	130	46	—	—
	6-1-70	87	90	56	130	47	—	—
	10-20-70	85	88	54	137	45	—	—
	6-23-71	82	85	51	139	46	—	—
	10-27-71	82	85	51	137	48	—	—
	6-00-72	65	71	33	129	47	—	—
	10-25-73	63	69	31	125	46	—	—
	6-00-74	78	82	47	121	43	—	—
	5-1-75	63	69	31	125	46	—	—
	5-12-76	57	64	25	127	46	—	—
	7-31-78	77	81	45	132	44	—	—
	3-29-80	86	89	55	133	47	—	—
26S/40E-1A02	3-9-54	—	—	—	84	—	—	24.4
	6-9-82	33	42	1	78	134	—	23.0
	6-17-85	143	137	116	79	166	162	24.5
26S/39E-3D01	4-27-46	96	97	66	127	53	—	—
26S/40E-1A01	7-8-53	—	—	—	40	137	—	20.0
26S/39E-2C01	4-26-46	98	99	68	163	44	—	—
25S/40E-35P01	7-4-53	—	—	—	65	114	38	21.7
	6-18-72	103	103	73	55	112	—	25.0
25S/39E-35N01	4-30-46	102	103	72	135	48	—	—
	7-3-53	—	—	—	140	52	—	20.0
	5-22-69	—	—	—	164	62	—	22.0
	10-20-70	87	90	56	124	48	—	—
	6-23-71	95	97	65	136	49	—	—
	10-27-71	85	88	54	134	45	—	—
	10-25-73	75	79	43	148	60	—	—

TABLE A-1. (Contd.)

| Location | Date | Type of geothermometer | | | | | | Measured temperature |
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	6-00-74	77	81	45	116	45	—	—
	5-12-76	93	95	62	107	42	—	—
	7-31-78	81	84	49	130	46	—	—
	3-29-80	89	92	59	126	48	—	—
2SS/40E-33L01	3-7-74	67	72	35	65	151	137	—
	3-25-75	63	69	31	70	146		19.0
	8-17-76	53	60	21	53	155	—	24.5
	6-21-78	111	110	81	56	150	—	23.5
	5-21-80	-31	-18	-63	199	288	—	21.5
	6-4-82	61	67	29	54	145	—	22.0
2SS/40E-33L02	3-7-74	31	39	-2	165	169	24	25.0
	3-25-75	24	33	-9	180	182	28	16.0
	8-17-76	19	29	-14	164	168	23	23.0
	6-21-78	26	35	-7	157	167	36	23.0
	5-31-79	-21	-8	-53	160	168	33	21.0
	5-2-80	111	110	81	158	170	29	20.0
	6-4-82	34	43	1	149	160	38	23.2
2SS/39E-31M03	5-22-69	—	—	—	125	61	—	—
2SS/38E-35M01	1-5-53	—	—	—	155	86	—	—
2SS/39E-31E01	4-26-46	55	62	23	111	70	44	—
	10-22-52	—	—	—	140	81	—	23.3
2SS/39E-31D01	10-21-52	—	—	—	127	59	—	23.0
2SS/38E-36B01	4-17-86	91	93	60	118	58	—	25.5
2SS/39E-28P01	4-26-46	109	109	80	171	44	—	—
2SS/41E-31C01	7-4-53	—	—	—	46	—	—	18.9
2SS/40E-2SH01	5-15-53	—	—		85	157	35	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
25S/39E-26H01	2-27-56	92	94	61	116	100	45	—
	10-14-63	—	—	—	74	—	—	—
	9-15-64	28	37	-5	90	115	—	—
	10-20-70	94	96	63	111	86	64	—
	6-23-71	105	105	75	118	84	38	—
	10-27-71	98	99	68	107	118	33	—
	6-6-72	65	71	33	136	95	34	—
25S/40E-27E01	7-9-53	—	—	—	181	168	38	20.6
	6-28-72	111	110	81	190	173	42	23.0
26S/39E-19Q01	4-5-55	—	—	—	155	41	—	30.0
	10-1-56	—	—	—	159	41	—	30.6
	9-19-57	—	—	—	166	43	—	30.0
	9-8-58	—	—	—	154	36	—	—
	11-20-59	—	—	—	164	46	—	30.6
	8-11-60	—	—	—	148	35	—	29.4
	8-1-61	69	74	37	175	42	—	—
	6-7-62	77	81	45	166	42	—	—
	4-00-63	79	83	48	84	16	—	—
	10-14-63	81	84	49	99	18	—	—
	5-5-64	83	86	52	179	49	—	—
	9-15-64	81	84	49	144	37	—	—
	6-21-65	69	74	37	155	39	—	—
	5-16-66	79	83	48	153	39	—	—
	9-7-66	78	82	47	138	33	—	—
	6-6-72	61	67	29	146	35	—	—
	6-00-74	61	67	29	139	39	—	—
	5-1-75	61	67	29	130	42	—	—

TABLE A-1. (Contd.)

| Location | Date | Type of geothermometer | | | | | | Measured temperature |
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	5-12-76	78	82	47	127	40	—	—
	7-31-78	69	74	37	156	41	—	—
	5-4-79	77	81	45	142	39	—	—
	3-27-80	78	82	47	147	38	—	—
26S/39E-19Q02	6-5-68	74	78	42	139	36	—	—
	11-4-68	75	79	43	140	36	—	—
	10-00-69	83	86	52	144	36	—	—
	6-00-70	77	81	45	144	37	—	—
	10-00-70	77	81	45	145	39	—	—
	6-00-71	85	88	54	159	40	—	—
	10-25-73	75	79	43	135	38	—	—
25S/40E-24N01	7-8-53	—	—	—	176	78	—	—
25S/39E-22J01	4-25-46	32	41	-1	164	166	—	—
25S/39E-19K01	4-25-46	59	66	27	220	82	38	—
25S/38E-23J01	4-16-86	79	83	48	230	62	—	22.5
25S/40E-20P01	10-21-52	—	—	—	236	96	—	18.9
	3-7-74	104	104	74	240	89	40	—
	3-29-75	101	102	71	255	97	32	20.5
	8-18-76	105	106	76	239	88	41	23.0
	6-20-78	21	31	-12	207	173	91	19.0
	5-16-79	36	45	3	115	56	—	20.0
	5-20-80	53	60	21	217	98	48	19.5
	6-4-82	77	81	45	225	93	45	20.8
25S/41E-19L01	7-4-53	—	—	—	103	100	—	22.2
25S/38E-23G01	4-24-46	72	77	40	184	62	—	—
25S/40E-24H01	5-15-53	—	—	—	85	157	35	—
25S/39E-24D01	4-25-46	—	—	—	223	80	41	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
2SS/39E-21B01	4-24-46	83	86	52	226	20	—	—
2SS/39E-22B01	4-25-46	89	92	59	230	78	50	—
2SS/41E-21E01	10-20-70	88	91	57	98	117	75	—
	6-23-71	102	103	72	127	97	66	—
	10-27-71	95	97	65	117	123	75	—
	8-25-73	91	93	60	95	115	92	—
	6-00-74	79	83	48	109	125	65	—
	5-1-75	79	83	48	90	109	97	—
	5-12-76	51	57	18	88	109	—	—
	7-31-78	69	74	37	91	100	49	—
2SS/40E-18R01	3-5-74	89	91	57	223	178	24	—
	3-24-75	91	93	60	245	190	24	16.5
	8-17-76	98	99	68	222	182	21	20.5
	6-21-78	65	71	33	228	262	207	22.0
	5-16-79	70	75	39	229	230	122	20.0
	5-20-80	84	92	59	252	230	91	22.5
	6-9-82	81	84	49	256	211	42	22.0
2SS/38E-13L01	6-15-82	78	82	47	203	62	—	25.0
2SS/38E-13E01	4-25-46	107	107	78	217	96	32	—
2SS/39E-17D01	4-24-46	36	44	3	265	73	65	—
2SS/38E-13D01	4-24-46	12	23	-21	275	220	—	—
2SS/39E-12R01	8-3-53	—	—	—	212	171	—	21.0
	7-31-78	85	88	54	194	92	38	—
	5-4-79	94	96	63	200	99	28	—
	3-29-80	97	98	67	222	177	29	—
2SS/39E-10Q01	4-24-46	115	114	86	225	85	—	—

TABLE A-1. (Contd.)

| Location | Date | Type of geothermometer | | | | | | Measured temperature |
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
25S/39E 12R02	4-20-55	—	—	—	116	55	—	—
	10-11-61	100	107	70	201	98	36	—
	7-18-62	103	103	73	196	162	19	—
	6-21-65	87	90	56	177	78	—	—
	5-16-66	98	99	68	116	59	—	—
	9-7-66	92	94	61	188	100	40	—
	10-7-67	95	97	65	191	159	21	—
	6-5-68	89	92	59	144	71	48	—
	11-4-68	95	97	65	185	94	38	—
	10-20-69	100	107	70	187	91	33	—
	6-1-70	113	112	84	195	98	34	—
	10-20-70	93	95	62	201	98	49	—
	6-00-71	99	96	63	114	55	—	—
	10-00-7	91	93	60	206	167	28	—
	10-25-73	93	95	62	181	94	44	—
	6-00-74	86	89	55	196	99	45	—
	5-7-75	79	83	48	195	99	33	—
	5-12-76	63	69	31	189	97	33	—
25S/39E - 12M01	5-14-53	—	—	—	148	167	107	18.0
25S/40E - 11K01	5-14-53	—	—	—	158	173	91	19.0
	7-6-53	—	—	—	160	174	49	19.0
	6-9-82	124	121	96	150	168	100	19.5
25S/39E - 9J01	8-3-53	—	—	—	200	81	34	23.0
	10-10-61	114	113	85	218	81	37	—
	7-18-62	105	106	76	200	82	34	—
	10-14-63	106	106	77	219	82	36	—
	9-15-64	101	102	71	183	68	—	—

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	5-16-66	103	103	73	193	75	53	—
	9-7-66	96	97	66	183	80	54	—
	00-00-67	104	104	74	199	82	35	—
	00-00-68	114	113	85	194	77	49	—
	6-5-68	100	101	70	204	79	44	—
	00-00-69	122	120	94	205	78	59	—
	5-2-69	—	—	—	245	95	30	—
	00-00-70	112	111	83	217	82	77	—
	00-00-71	98	99	68	206	79	42	—
	00-00-72	83	86	52	199	77	52	—
	10-25-73	100	101	70	202	72	56	—
	6-00-74	100	101	70	206	77	56	—
	5-1-75	92	94	61	215	84	34	—
	5-12-76	104	104	74	208	73	42	—
	7-31-78	105	105	75	206	77	39	—
	5-4-79	98	99	68	189	79	—	—
	3-27-80	108	108	79	209	82	41	—
25S/38E-11K02	6-5-53	—	—	—	189	60	—	—
	8-5-53	—	—	—	200	65	—	—
25S/39E-07K01	4-23-46	32	41	-1	180	165	—	—
25S/39E-10G01	4-23-46	12	23	-21	209	188	34	—
25S/40E-8A01	7-4-53	—	—	—	227	199	—	—
	3-5-74	106	106	77	222	192	37	—
	3-24-75	103	103	73	244	203	39	18.0
	8-17-76	111	111	82	222	192	31	20.0
	6-20-78	107	107	78	217	188	23	20.5
	5-16-79	111	110	81	222	191	32	20.5

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
	5-20-80	55	62	23	219	190	28	19.5
	6-4-82	114	113	85	212	184	27	20.0
2SS/39E-1N01	4-25-46	96	97	66	217	173	—	—
2SS/39E-4R01	8-5-53	—	—	—	205	92	—	23.0
	10-10-61	97	98	67	212	96	—	—
	7-18-62	95	97	65	202	98	—	—
	10-14-63	92	94	61	212	97	—	—
	9-15-64	81	84	49	180	81	33	—
	5-16-66	89	92	59	207	95	39	—
	9-7-66	86	89	55	185	95	47	—
	00-00-67	88	91	57	206	97	—	—
	00-00-68	91	93	60	195	99	—	—
	6-5-68	82	85	51	148	71	—	—
	00-00-69	95	97	65	200	99	34	—
	00-00-70	78	82	47	212	95	33	—
	00-00-71	88	91	57	212	95	—	—
	6-00-72	72	77	40	256	204	—	—
	10-25-73	88	91	57	189	89	41	—
	6-00-74	77	81	45	237	183	21	—
	5-1-75	72	77	40	194	91	—	—
	5-17-76	94	96	63	191	95	—	—
	7-31-78	86	89	55	205	92	30	—
	3-29-80	89	92	59	212	169	22	—
2SS/39E-2E01	4-23-46	96	97	66	204	81	41	—
24S/40E-33N01	7-6-53	—	—	—	112	155	121	20.0
24S/39E-33N01	4-23-46	36	44	3	249	195	—	—
24S/39E-33J02	6-00-72	—	—	—	323	48	—	—
	6-15-82	88	91	57	231	60	—	25.0

TABLE A-1. (Contd.)

Location	Date	Type of geothermometer						Measured temperature
		Quartz conductive cooling	Quartz steam flashing	Chalcedony conductive cooling	Na-K	Na-K-Ca	Na-K-Ca-Mg	
24S/40E-34E01	7-8-53	—	—	—	208	84	79	23.0
24S/38E-35E01	4-24-46	42	50	10	177	158	19	.—
24S/39E-33D01	2-3-20	94	96	63	—	—	—	—
	4-23-46	28	37	-5	214	181	19	—
24S/38E-28Q01	8-5-53	—	—	—	231	71	—	26.0
24S/40E-20J01	5-15-53	—	—	—	193	162	—	21.0
24S/38E-16J02	6-15-82	79	83	48	173	153	—	25.5
24S/40E-6A01	4-24-46	18	28	-15	177	192	—	—
23S/38E-17D01	7-13-55	—	—	—	209	97	32	—
	9-4-59	99	100	69	209	164	—	22.0
23S/38E-8D01	7-15-55	—	—	—	217	84	37	—
23S/38E-5N01	7-13-55	—	—	—	195	91	34	—
	7-30-60	100	101	70	167	95	31	—